MEDDOCS Open Access Publisher

Annals of Clinical Nutrition

Open Access | Research Article

Relationship between meat consumption and greenhouse gas emissions

***Corresponding Author(s):** Ampere A Tseng

Director and Professor Emeritus, Manufacturing Institute, Arizona State University, USA

Tel: (602) 810-1084, Fax: (480) 965-1384

Email: ampere.tseng@asu.edu

Received: Apr 22, 2018

Accepted: Jun 20, 2018

Published Online: Jun 25, 2018

Journal: Annals of Clinical Nutrition

Publisher: MedDocs Publishers LLC

Online edition: http://meddocsonline.org/

Keywords: Food consumption; Greenhouse gas emission; Group of twenty; Human dietary behavior; Meat consumption, World

Abstract

Correlation formulas are developed to estimate the dietary and total greenhouse gas emissions (GHGEs) from the nineteen countries of the Group of Twenty (G20) and the world using personal meat consumption as the only input. Based on 47,381 dietary survey samples, quadratic formulas are developed to correlate the meat consumption with GHGEs from human dietary and total activities. The formula reliability is established by comparing formula predictions with peer-reviewed results. These formulas could provide benchmark information for strategy development for reducing GHGEs in order to mitigate the global warming problems. The present study finds that, from 2013 to 2015, the daily dietary GHGE per capita of the nineteen countries varies widely from 4.11kgCO_2e from India to 8.71kgCO_2e from the USA. In 2013, the contribution of the dietary GHGE to the total GHGE changes from 11% for Canada to 63% for India while the world average is 32 %. From 2013 to 2015, the total GHGE changes among the nineteen countries are from a 1.7%-reduction in Russia to a 4.0%-increase in Turkey. Furthermore, the formulas predicate that the global dietary and total GHGEs increase monotonically from 15.9 and 49.5 GtCO_2e in 2015 to 17.7 and 55.4 GtCO_2e in 2025, respectively.

Highlights

- Correlation Formulas are developed to estimate dietary and total greenhouse-gas emissions.
- The greenhouse-gas emissions of nineteen major countries in 2015 are evaluted.
- The greenhouse-gas emissions of the world from 2015 to 2025 are predicted

Introduction

The food production system is a major contributor to global GHGEs, which are produced at all stages in the system [1]. The Food Climate Research Network estimated that the food system in UK in 2008 accounts for 18.4% of all the GHGEs generated by human activities [2,3] reported that the production of livestock accounts for 18% of the GHGEs; based on a land-use model and also estimated that the cumulative GHGEs in the period from 2010 to 2050 could be up to 20% lower if all people would be vegetarians. Li et al. [4] studied the food chain systems in China, beginning with agricultural production and ending with consumption and waste disposal. They projected that, based on existing trends, the GHGEs increases from 1.585 Gigaton (Gt) of CO_2e in 2010 to 2.505 GtCO_2e in 2050, which represents a 58% increase within 40 years. However, although the GHGE can grow with rising food demand, the growth can be counterbalanced by eating more plant-based food. This can cause the GH-

Cite this article: Tseng AA. Relationship between meat consumption and greenhouse gas emissions. Ann Clin Nutr. 2018; 2: 1007.

GEs to fall to 1.118 $GtCO_2e$ by 2050, a 30% reduction compared with the level in 2010.

Despite being one of the major causes of anthropogenic GHGEs, the GHGEs from food consumption or dietary GHGEs seldom get attention and are rarely reported by international organizations or government agencies, although the dietary GHGE data is essential in managing the total GHGEs and in reducing dietary GHGEs. Consequently, one of the purposes of this article is to develop a correlation formula to estimate the dietary GHGEs using meat consumption as the only required input data. The formula reliability is demonstrated by comparing formula predictions with published data by other approaches. The dietary GHGE and its contribution to the total GHGE for the 19 countries of the Group of Twenty (G20) are then studied in order to illustrate the simplicity and versatility of the formula developed.

The correlation formula is further enhanced to predict the global dietary and total GHGEs from 2015 to 2025 by assuming that the global dietary or human behavior follows the current trend without major changes as those recommended by Hawken [5]. It is noteworthy that meat consumption is related to socioeconomic conditions, including living standards, diet, livestock production, and consumer prices and that the meat production has significant environmental and economic consequences for the earth [6]. Also, meat is a major commodity and meat consumption data are frequently provided by many international organizations [7,8].

The 19 countries in G20 considered including Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, South Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, United Kingdom (UK) and United States (US), are not only major economies but also major GHG emitters. Understanding the amount of dietary and total GHGEs from the major emitters is essential in developing an effective strategy for reducing the GHGEs in order to mitigate the global warming challenges. In the present study, the last G20 member, the European Union (EU), is replaced by the whole world and the associated global results are serving as the benchmark for the comparison with that of the 19 countries.

Correlation of meat consumption with dietary greenhouse-gas emissions

The dietary survey from 47,381 participants and the corresponding carbon-footprint or GHGE data reported by Scarborough et al. [9] are adopted and analyzed to develop correlation formulas to estimate the dietary and total GHGEs. The survey data are placed into five dietary groups: vegan (2,041 samples), vegetarian (15,751 samples), low-in-meat eater (9,332 samples), medium-in-meat eater (11,971 samples) and high-in-meat eater (8,286 samples). The low-in-meat eaters consume meat less than 50g daily while the high-in-meat eaters consume meat more than 100g/day. Both vegans and vegetarians do not eat any meat. Although vegans avoid all animal products, vegetarians can consume dairy products and eggs.

The dietary data for the five groups considered are summarized in Table 1 in the 2nd and 3rd columns for the daily meat consumption per capita (MC_d) and the daily dietary GHGE per capita ($GHGE_{dd}$) respectively. Here, the Sampling Interval (SI) is controlled with the statistical significance at the 5% level while the Confidence Interval (CI) is in 95%. As indicated in Table 1, three places are marked with "?" because more data are needed in these places for the correlation analysis to be performed; these are not provided by the source article of Scarborough et al. [9]. Firstly, the upper bound of the Sampling Interval (SI) for the high-in-meat eaters is not specified (? mark in the 2nd row of 2nd column). Secondly and thirdly, we cannot have two GHGE values for the initial condition (IC) or at $MC_d = 0$ in a correlation analysis; as shown in Table 1 (? marks in the 5th & 6th rows of 2nd column), $MC_d = 0$ for both vegan and vegetarian groups.

To determine the appropriate values for the three-additional data required, we perform two cases of correlation analyses with different assumptions. The correlation results for the two cases are then used to judge which assumptions is the most appropriate for predicting $GHGE_{dd}$.

Correlation between meat consumption and greenhouse-gas emissions (Case 1)

In Case 1, we assume that the MC_d range for the high-in-meat group is from 100 g to 150 g having an SI of 50 g, which is same as that of the medium-in-meat and low-in-meat, as indicated in the 2nd column of Table 1. Two ICs: IC-1 and IC-2 are evaluated, where IC-1 is based on the vegan data, i.e., at $MC_d = 0$, $GHGE_{dd} = 2.89$ $kgCO_2e$, while IC-2 is from the vegetarian data, at $MC_d = 0$, $GHGE_{dd} = 3.81$ $kgCO_2e$.

The correlation results are shown in Figure 1, where the solid and dotted lines represent the results with IC-1 and IC-2, respectively. The correlation coefficients, R^2, are also displayed in the figure, where $R^2 = 1$ means a perfect match of the two variables correlated. As shown, both correlation curves fit the data very well, since the associated R^2s are all higher than 0.96. The correlation with IC-2 (dotted line, vegetarian data) is slightly better, since its R^2 is about 3% higher than that of the vegan data (IC-1). However, the correlation curves outside the region of $MC_d > 125g$, do not agree with each other very well, and the associated trend lines appear to diverge from each other, which implies that the assumptions made in Case 1 are not appropriate and the MC_d range needs to be reconsidered with one IC. The appropriate assumptions for MC_d and IC are analyzed in the next subsection.

Correlation of equivalent meat consumption with greenhouse-gas emissions (Case 2)

In Case 2, the mean $GHGE_{dd}$ for the vegan group, i.e., 2.89 $kgCO_2e$, is singled out as the IC (at $MC_d = 0$). Consequently, the mean $GHGE_{dd}$ for vegetarians, i.e., 3.81 $kgCO_2e$, should not be the IC. To determine what is the corresponding MC_d value for $GHGE_{dd} = 3.81$ $kgCO_2e$ for the vegetarian group, a parameter called equivalent meat consumption (MCe) is introduced. The corresponding MCe for the vegetarian group is determined by considering the $GHGE_{dd}$ difference between the vegetarian and the vegan group, i.e., 0.92$kgCO_2e$ (= 3.81-2.89). The 0.92 $kgCO_2e$ should be the $GHGE_{dd}$ due to the additional consumption of eggs and/or dairy products minus the $GHGE_{dd}$ due to less consumption of plant-based food. Applying the MCe parameter, it can be found that $GHGE_{dd} = 2.89$ $kgCO_2e$ at MCe = 0, and $GHGE_{dd} = 3.81kgCO_2e$ at MCe = 41.73g [10]. Thus, MCe [g] = MC_d [g] + 41.73g for $MC_d > 0$. Also, in Case 2, two SIs: SI-1 = 50g and SI-2 =100g, for the high-in-meat group are selected for the analysis. The corresponding MCe range for SI-1 condition is $141.73 \leq MCe < 191.73$ (SI-1) and for SI-2 condition is $141.73 \leq MCe < 241.73$.

The correlation results for Case 2 are depicted in Figure 2, where the dotted and solid lines represent the results based on

SI-1 and SI-2 conditions, respectively. As shown in the figure, both correlations fit the data points extremely well, since the corresponding correlation coefficients (R^2) are higher than 0.99, almost perfect. As shown in Figure 2, the dotted-line correlation curve (based on SI-1) almost monotonically increases with MCe. In general, an increase of MCe can cause a reduction of plant food consumption based on the same amount of food-energy (calories) diets. As a result, the increase rate of GHGE should be gradually reduced to counter the reduction of plant food consumption. Thus, the linear increase of $GHGE_{dd}$ with MCe shown in the dotted line of Figure 2 (using SI-1 condition) does not reasonably reflect the true correlation of MCe to $GHGE_{dd}$. It is believed that using the SI of 50 g (SI-1) is not large enough to cover all the sampling data for the high-in-meat group, because many of the survey participants consume more meat than the range (more than MC_d >150 g) considered in SI-1.

Consequently, as shown in Figure 2, the growth rate of the solid-line curve (based on SI-2) is gradually decreasing as MCe increases; the solid-line curve provides more reasonable prediction of $GHGE_{dd}$ for the range considered. Also, the R^2 of the solid-line curve (SI-2 condition) is higher than that of the dotted-line curve (SI-1 condition), which means that Case 2 with SI-2 condition provides more accurate correlation than that of SI-1 condition. Furthermore, by reviewing the raw survey data, very few survey participants consume meat more than 200g (MCe = 241.73g). As a result, the correlation of Case 2 with SI-2 condition should be adopted as the correlation formula to quantify the relationship between $GHGE_{dd}$ and MCe.

Correlation formulas between dietary emission and personal meat consumption

As indicated in the analysis presented in the preceding sections, the correlation result of Case 2 with SI-2 condition shown in Figure 2 is adopted to form the formulas to quantify the dietary $GHGE_{dd}$ using MC_d as the input. Since MCe [g] = MC_d [g] + 41.73 [g], the correlation formulas can be found as:

for $MC_d > 0$ (meat-eater groups),

$GHGE_{dd} = -2.0\times10^{-5} (MC_d + 41.73)^2 + 0.0264 (MC_d + 41.73) + 2.8664$, ---------(1a)

for $MC_d = 0$ and $MCe > 0$ (vegetarian group),

$GHGE_{dd} = 3.81$, ---------(1b)

and for $MC_d = 0$ and $MCe = 0$ (vegan group),

$GHGE_{dd} = 2.89$, ---------(1c)

where $GHGE_{dd}$ is in [$kgCO_2e$]; MCe and MC_d are in [g].

Meat consumption for dietary emission evaluations

To estimate $GHGE_{dd}$, the input data of MC_d is required for 19 countries and the world considered, this section also present the evaluation of the dietary GHGEs.

Meat consumption and personal dietary GHGE

Except four European counties: France, Germany, Italy, and UK, OECD [7] provides the annual meat consumption per capita for all other 15 of the 19 countries considered for 2013 and 2015. The meat consumption data are tabulated in kg of retail weight for the "Big-Four" livestock, i.e., beef/veal, pork, poultry, and sheep.

For the four European countries: France, Germany, Italy, and UK, the FAO data [11] are adopted. Since FAO's data are based on DW, they need to be converted from DW to RW by multiplying the yield of 0.803 and then converted from RW to MW by a yield of 0.92.

The input data of meat consumption in retail weight in 2014 and 2017 can be found from the data provided by OECD [7], which were tabulated in kg of retail weight for the "Big-Four" livestock, i.e., beef/veal, pork, poultry, and sheep. The total weight of the annual Meat Consumption (MCa) in kg/capita for the fifteen G20 states and the average of the 28 states of EU are listed in the 2nd column of Table 2 for 2014. In the present study the 28 states of EU (EU28) are considered as a whole and as a single entity. Since the four states in EU28, which overlap with those of G20 members, are already counted in EU28, only 15 (= 19-4) states of the G20 plus EU28 and the world are studied.

On the other hand, in response to the UK dietary survey, the participants are most likely reporting their meat consumption in either Cooked Weight (CW) or RW. According to Scarborough, et al. [9], the meat consumption data in their survey, which are used to develop Eq. (1a), have not been distinguished between the meat consumed being raw and being cooked. In fact, the survey participants usually report their meat consumptions by using the weight labeled on the meat product purchased from supermarkets or grocery stores, where both the raw and cocked meats are sold. Many of cocked meats, such as roasted meats, barbecue meats, sliced deli meats, and cooked ham are sold in typical supermarkets or grocery stores. Also, the participants can report the CW displayed on menus, when they eat at restaurants or similar places. Furthermore, the participants can measure their cooked food before eating as indicated in many websites [12,13]. Consequently, in this article, it is assumed that one-third of meat consumption data used to develop Eq. (1a) are based on CW and the other two-thirds are based on RW. Thus, for the sake of clarity of the presentation, the weight of meat consumption used in Eq. (1a) is called 'Mixed Weight (MW)'.

Normally, CW is less than RW due to the moisture and fat being drawn out during the cooking process. There is no one yield value for converting RW to CW for meat, because there are a lot of factors, such as cooking methods, meat quality, cooking temperature, cooking time etc. to account for. The US Department of Agriculture reports an extensive study on the cooking yields for more than two-hundred different processes in cooking meat [14]. The cooking yields reported vary from 0.29 for microwaving pork to 0.96 for baking or roasting pork ham. The major cooking yields are between 0.65 and 0.85, which are also consistent with other private estimations [15]. The average yield of 0.75 is thus selected for the present calculation, in which one-third of the survey data for meat consumption is based on CW. The average yield for converting the OECD or FAO data from RW to MW used in the present calculation becomes 0.92.

Meat consumption of G20 in 2013 and 2015

In studying the dietary GHGEs in both 2013 and 2015, the annual meat consumption per capita data in RW (MC_a) in 2013 and 2015 reported by OECD [7] and FAO [11] are selected. Except four European countries: France, Germany, Italy, and UK, OECD provides data for all other 15 of the 19 countries considered. As discussed in the preceding subsection, the yield value of 0.92 is needed to adjust the OECD data to have the meat in MW, which is required by Eq. (1a). As an example, based on OECD data, the MC_a of Argentina is 84.6 kg in RW and the MC_d of Argentina becomes 213.2gMW, i.e., 84.6kgRW x 0.92 (yield from RW to MW) x 1000/365, where there are 365 days in the year of 2013. Following the same procedure, the MC_d for the other 14 countries and the world can be calculated. Both MC_a data and MC_d results for the 15 countries mentioned are listed in the 2nd and 3rd column of Table 2, respectively.

For the four European countries: France, Germany, Italy, and UK, the FAO data [11] are adopted. Since FAO's data are based on DW, they need to be converted from DW to RW by multiplying the yield of 0.803 and then converted from RW to MW by a yield of 0.92. For example, the annual meat consumption of France is 86.67kg in DW, the MC_d of France becomes 175.6gMW, i.e., 86.76kgDW x 0.803 x 0.92 x 1000/365. For the sake of consistence, the FAO data for the 4 European countries shown in the 2nd column of Table 2 are already converted from DW to RW. Moreover, the FAO data are also verified by comparing the global consumption of the FAO data in 2013 with that of the OECD data, because both FAO [11] and OECD [7] report the total meat consumption in DW.

Since FAO data are not available for 2015, the 2013 FAO data for the four European countries are modified to be used as the 2015 data. OECD (2016) has the average meat consumption data for the European Union (EU28) in both 2013 and 2015, which changes from 64.9kgRW in 2013 to 68.3kgRW in 2015, an increase of 5.24%. Consequently, the data for the four countries in 2015 are using their 2013 data with an adjustment of a 5.24%-growth. The 2015 MC_a data for all 19 countries and the world in [kgRW] are summarized in the 2nd column of Table 3. Both the OECD [7] and FAO [11] data count the amount of the meat consumption for the "Big-Four" livestock, i.e., beef/veal, pork, poultry, and sheep.

Dietary emissions from G20 countries and the world in 2013

In this section, the MC_d calculated earlier is used to estimate $GHGE_{dd}$ for the 19 countries of G20 in 2013. The $GHGE_{dd}$ are then compared with the daily total GHGE ($GHGE_{td}$) to establish a correlation for the predication of future $GHGE_{td}$.

Estimation of daily dietary emissions per capita in 2013

Using the MC_d data earlier reported in the 3rd column of Table 2 as an input to Eq. (1a), the $GHGE_{dd}$ from the 19 countries of G20 and the world in 2013 can be estimated. For example, by substituting 213.2gMW (the MC_d of Argentina) into Eq. (1a), the $GHGE_{dd}$ from Argentina can be obtained to be 8.30 $kgCO_2e$. Following the same procedure, the $GHGE_{dd}$ from the other 18 countries and the world in 2013 can be found and all results are reported in the 4th column of Table 2.

As shown in Table 2, the $GHGE_{dd}$ varies noticeably from 4.11$kgCO_2e$ from India to 8.61$kgCO_2e$ from Australia in 2013. The global average is 5.90$kgCO_2e$. The maximum $GHGE_{dd}$ is more than twice larger than the minimum $GHGE_{dd}$, which implies that there is a reasonably big room for the heavy meat-eater countries to mitigate their dietary GHGEs by promoting plant-based diets.

Correlation formula for dietary emission with meat consumption in retail weight

Equation (1a) can be re-correlated MC_a (not MC_d) in [kgRW] (the 2nd column of Table 2) with $GHGE_{dd}$ in [$kgCO_2e$] (the 4th column of Table 2) directly. The re-correlated formula can be found as:

$$GHGE_{dd} = -1.2706\times10^{-4}MC_a^{\,2} + 0.062258MC_a + 3.9332 \text{ --------- (1d)}$$

where MC_a is in [kgRW] and $GHGE_{dd}$ is in [$kgCO_2e$]. The above equation should be adopted for later $GHGE_{dd}$ predictions to eliminate the steps for meat-weight conversion.

Comparison of dietary emissions with total emissions in 2013

The World Resources Institute through its Climate Analysis Indicators Tool [16] website provides historical GHGE data for many countries. There are two types of CAIT data reported: Total GHGEs Excluding Land-Use Change and Forestry and Total GHGEs Including Land-Use Change and Forestry. As required by the UN Climate Change Secretariat, the GHG inventory sector should cover the emissions and removals of GHGs resulting from direct human-induced land use, land-use change, and forestry activities. Except USA, the CAIT [16] data including the Land-Use Change and Forestry activities are adopted for the 18 countries and the world, while the US data is obtained from its Environmental Protection Agency [17]. All the national total GHGE data ($GHGE_{tn}$) for the 19 countries and the world in 2013 are listed in the 5th column of Table 2.

The population data for the 19 countries and the world in 2013 from UN Population Division [18] are listed in the 6th column of Table 2. With the population data, the $GHGE_{tn}$ can be converted to the personal daily total GHGE ($GHGE_{td}$) and are summarized in the 7th column of Table 2.

To estimate the contribution of $GHGE_{dd}$ (in the 4th column of Table 2) to $GHGE_{td}$ (in the 7th column of Table 2), the Ra_{dt} ratio (= $GHGE_{dd}$ /$GHGE_{td}$) can be obtained and are shown in the 8th column of Table 2. As shown, the contribution of the dietary GHGE to the total GHGEs in 2013 varies from the lowest 11% from Canada to 63% from India depending on the specific country considered, where the corresponding global average is 32%. The wide variation of the Ra_{dt} ratio among the 19 countries of G20 implies that the food system in each country considered is greatly influenced by not only the dietary behavior of the people in each country but also its socioeconomic conditions [6]. Note that the Ra_{dt} ratio is going to be used as a weighting function for the predications of the $GHGE_{td}$ from 2015 to 2025.

Comparison of present estimation of dietary emissions with other published results

In 2006, the world per capita meat production (MC_a) reported by OECD [7] is 31.5kgRW**.** By adjusting the weight from RW to MW, the yield of 0.92 is again used. Thus, the daily per capita meat consumption (MC_d) can be found to be 79.4gMW (= 31.5 x 0.92 x 1000/365). Using Eq. (1d) and MC_a = 31.5kgMW**,** the $GHGE_{dd}$ can be found to be 5.77$kgCO_2e$**.** Since the world population is 6.6×10^9 in 2006 [18], the annual dietary GHGE of the world can be found to be 1.39×10^{13} (= 5.77 x 6.6×10^9 x 365) $kgCO_2e$ or 13,900 $MtCO_2e$. Since the world's total GHGE in 2006 was 42.779 $GtCO_2e$ (including land-use change and forestry) [15], the present prediction of the GHGEs from the food consumption is 32.5% (= 100 x 13,900/42,779) of the total human GHGE. In addition, based on the most recent data by CAIT (2016), the total global GHGE in 2013 is 48.257 $GtCO_2e$. The dietary GHGE can be calculated from Eq. (1d) and is also 32.5% of the total global GHGE. The above calculation is based on that MC_a is 34.1kgRW provided by OECD [7] and the world population is 7,349 million in 2013 [18].

In 2006, Tukker and Jansen [19] reported that GHGEs from food consumption accounts for approximately 31% of total GHGEs in the EU-25. Also, according to Garnett [20] the GHGE associated with the food system rises to up to 30% when additional emissions from fuel use, fertilizer production and agriculturally induced land use change are included. By comparing with the 31% and 30% of the total GHGEs reported by Tukker & Jansen [19] and Garnett [20], respectively, the present predication of 32.5% is less than 5% and 10% higher than that reported by Tukker & Jansen and Garnett, respectively.

In a more recent study, Vermeulen et al. [21] estimated that, the GHGE for food systems releases from 9.8 to 16.9 $GtCO_2e$, which is consistent with the present estimation of 13.9 $GtCO_2e$. Furthermore, Fiala [22] assessed that the emission from meat production is accounting for between 15% and 24% of the total GHGEs. As estimated by Friel et al. [23] 80% of agricultural emissions (from both meat-based and plant-based food production) arise from the meat production sector. Thus, based on the Fiala's estimation, the GHGEs from both meat and plane-based food consumption contribute between 18.75 (15/0.8) and 30.0 (24/0.8) % of total GHGEs.

Based on the comparison presented above, the present prediction is less than 5% to 10% higher than that reported by other studies and the differences are relatively small. Consequently, the present prediction can be considered reasonably reliable and can also be considered an upper-bound estimation.

Enhanced correlation for predicating dietary and total emissions beyond 2013

As mentioned earlier, meat consumption is related to socioeconomic conditions and is characterized by high production costs and associated with higher incomes. Thus, the meat consumption should have significant economic and environmental consequences. In this section, the meat consumption is further correlated with the total GHGEs. Both the dietary and total GHGEs for the 19 countries of G20 in 2015 and for the world from 2015 to 2025 are estimated.

Estimation of dietary emissions of G20 countries and the world in 2015

Using Eq. (1d) with the MC_a data provided by OECD [7] or by FAO [11] (in the 2nd column of Table 3), the $GHGE_{dd}$ for the 19 countries considered can be calculated and shown in the 3rd column of Table 3. As shown, in 2015, the $GHGE_{dd}$ varies noticeably from 4.11$kgCO_2e$ from India to 8.71$kgCO_2e$ from USA. The global average of $GHGE_{dd}$ is 5.91$kgCO_2e$ increasing 0.17% as comparing to that of 2013.

Estimation of total emissions ($GHGE_{td}$) of 19 G20 countries in 2015

Equation (1d) establishes the correlation between MC_a and $GHGE_{dd}$ while Ra_{dt} (in the 8th column of Table 2) is the ratio of $GHGE_{dd}$ to $GHGE_{td}$. Thus, Eq. (1d) can be combined with the Ra_{dt} ratio to correlate MC_a to $GHGE_{td}$ as:

$$GHGE_{td} = (-1.2706\text{x}10^{-4}MC_a^{\ 2} + 0.062258MC_a + 3.9332)/Ra_{dt} \quad \text{---------}(2)$$

where MC_a is in [kgRW] and $GHGE_{td}$ is in [$kgCO_2e$]. If the dietary behavior is not changed very much for the countries considered from 2013 to 2015, the above equation can be used to predict the $GHGE_{td}$ in 2015 using the 2015 meat consumption data reported earlier (in the 2nd column of Table 3), the 2015 population data by UNPD [18] (in the 5th column of Table 3) and the Ra_{dt} values in 2013.

The results based on Eq. (2) for the national total GHGE ($GHGE_{tn}$) for the 19 countries and the world are summarized in the 6th column of Table 3. The results indicate that, from 2013 to 2015, the $GHGE_{tn}$ changes in these 19 countries are from a 1.7%-reduction of $GHGE_{tn}$ from Russia to a 4.0%-increase of $GHGE_{tn}$ from Turkey, while the whole world emits 2.5% more GHG, growing from 48.257 to 49.453 $GtCO_2e$.

As shown in Table 3, the average growth of $GHGE_{tn}$ of the 19 G20 countries from 2013 to 2015 is 1.8%, which is about 28% lower than that of global $GHGE_{tn}$. This 28% difference implies that there is a big room for the global efforts in the reduction of global $GHGE_{tn.}$ Also, based on the CAIT [16] estimation (including land-use change and forestry), the world emits 47.59 $GtCO_2e$ in 2012 and 48.26 $GtCO_2e$ in 2013. The corresponding annual growth rate of the global $GHGE_{tn}$ is 1.40% which is about 12% lower than that of the average growth rate of the global $GHGE_{tn}$ from 2013 to 2015, i.e., 1.25% ($101.25\%^2 = 102.5\%$, which reported in the 7th column of Table 3).

Predictions of dietary and total emissions of the world from 2015 to 2025

OECD [7] has studied the trend of the meat consumption of many different countries and has predicted the global meat consumption from 2015 to 2025. Based on the meat consumption data from OECD [7], which are listed in the 2nd column of Table 4, the global dietary ($GHGE_{dd}$) and total ($GHGE_{td}$) GHGEs from 2015 to 2025 can be calculated from Eqs (1d) and (2), respectively. The corresponding results are presented in the 3rd and 4th columns of Table 4. As shown in Table 4, $GHGE_{dd}$ and $GHGE_{td}$ are monotonically increasing from 5.91 and 18.43 kg-CO_2e in 2015 to 5.97 and 18.63 $kgCO_2e$ in 2025, respectively. Since Eqs (1d) and (2) only consider the effects of changing diets but not consider the technology improvement in producing the human food, it is not surprised that GHGEs are monotonically growing as the meat consumptions, which are monotonically increasing. If the food production technology has reasonable improvement, the future $GHGE_{dd}$ and $GHGE_{td}$ can have reasonable reduction.

Using the population data predicted by UNPD [18], the $GHGE_{dn}$ and $GHGE_{tn}$ from 2015 to 2025 can be estimated from the results of $GHGE_{dd}$ and $GHGE_{td}$ just calculated. The corresponding results are listed in the 6th and 7th columns of Table 4. Again as indicated in Table 4, the estimated results of $GHGE_{dn}$ and $GHGE_{tn}$ are monotonically increasing from 15.85 and 49.45 $GtCO_2e$ in 2015 to 17.75 and 55.38 $GtCO_2e$ in 2025. The $GHGE_{dn}$ and $GHGE_{tn}$ increase with an average annual growth rate of 1.16%. Again, if the green-energy related technology can be greatly improved and the human activities in energy saving can be implemented, the future $GHGE_{dn}$ and $GHGE_{tn}$ can be greatly lower as estimated by Hawken [5]. Also, having a sizable change of the human dietary behavior by switching to more plant-based food can help to mitigate GHGEs. Otherwise, if the current trend continues, it would be inevitable to exceed the 2C limit imposed by the Paris Climate Agreement in a near future.

Concluding Remarks

Correlation formulas are developed based on a dietary survey with 47,381 participants to estimate the Greenhouse Gas Emissions (GHGEs) from human food consumption and total activities for the 19 countries of G20 and the world. The correlation results show that the daily dietary GHGE per capita in 2013 varies widely from 4.11kgCO_2e in India to 8.61kgCO_2e in Australia, while the global average is 5.90kgCO_2e. The maximum dietary GHGE is more than twice higher than the minimum one, which implies that there is a reasonably large room for the heavy meat-eater countries to mitigate their dietary GHGEs by switching to more plant-based diets.

In 2015, the total GHGE among the 19 countries considered varies from 357 MtCO_2e in Turkey to 11,550 MtCO_2e in China. The wide variation of the GHGEs implies that the food system in each country considered is greatly influenced by not only the dietary behavior of the people but also its socioeconomic conditions. As a result, for the development of an effective strategy or green technology to reduce the GHGEs, the impact of the socioeconomic and technological conditions on the dietary and total GHGEs should be essential and worthwhile for further study.

The ratio of dietary GHGE to the total GHGE in 2013 is calculated. The ratio among the 19 countries varies from the lowest 11% in Canada to 63% in India, while the world average is 32%, which is consistent with other published results obtained by using different approaches. This demonstrates that the correlation formulas developed are not only simple, but also reliable.

The growths of the total GHGEs from 2013 to 2015 are estimated. The results indicate that, from 2013 to 2015, the total GHGE changes in these 19 countries are from a 1.7%-reduction in Russia to a 4.0%-increase in Turkey. The whole world is found to emit 2.5% more greenhouse gases, increasing from 48,257 in 2013 to 49,453 MtCO_2e in 2015, with an annual growth rate of 1.25%, which represents a 12% of emission reduction as compared with the annual rate from 2012 to 2013.

Furthermore, if the current trend is persistent, the present study predicates that the global dietary and total GHGEs increase monotonically from 2015 to 2025 with an annual growth rate varying between 0.99% and 1.32%. It is believed that the new green technologies to every sectors of industry have to be developed and the managing plan and technology to reduce human energy consumption has to be implemented or improved. Otherwise, it should be very difficult for not exceeding the 2C limit imposed by the Paris Climate Agreement. Certainly, switching the dietary behavior to have more plant-based diets can also help in mitigating the GHGEs.

More dietary surveys are recommended to be conducted to provide data with more dietary groups with smaller sample interval, i.e., more than the five groups and smaller than 50-g sample interval considered; so that more accurate and reliable correlations can be developed.

Mathematically, the national GHGE is a geographical and temporal variable, depending on the specific country and year considered. As suggested by the form of Eq. (2), the geographical effect is managed by the ratio Ra_{dt}, while the temporal effect is handled by the changes of MC_a. The current approach in developing Eq. (2) is similar to the simplest first-order forward scheme of the finite difference method, where the effects of geographical and temporal are also separately treated and each effect is taken care by a set of finite difference approximations. To improve the reliability of the correlation developed, the ratio, Ra_{dt}, should be updated every few years. This ratio may need to be further improved to include time-effect predictability by compiling more data on both technological improvements and socioeconomic changes in each nation considered, so that the prediction can be more accurate and reliable.

Figures

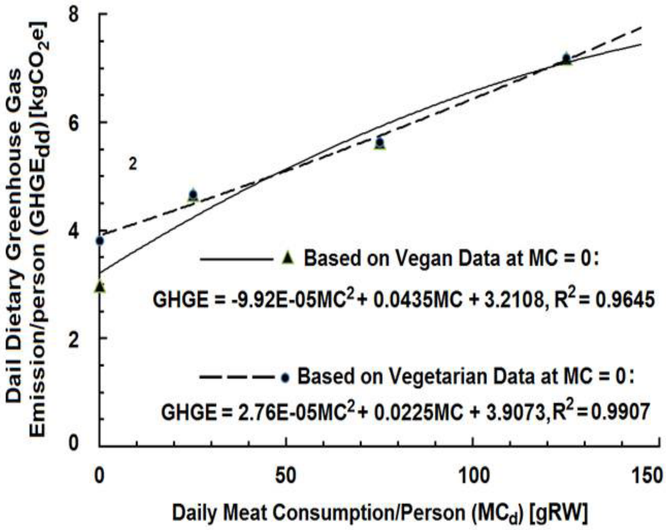

Figure 1: Correlation of dietary emission with daily meat consumption (MC_d) for Case 1.

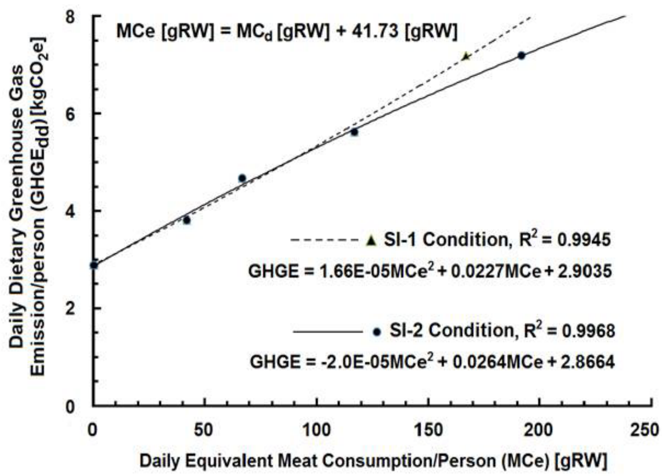

Figure 2: Correlation of dietary emission with equivalent meat consumption (MCe) for Case 2.

Tables

Tables 1: Carbon-footprint data and conditions adopted for correlation analysis.

Dietary group	Original SI[1] for MC_d[2] [g]	Mean $GHGE_{dd}$[3] & 95%-CI[4]	MCe[5] range for Case 2 with SI-2 condition	Mean of MCe [g]	Mean $GHGE_{dd}$ [$kgCO_2e$]
High-in-meat	$100 \le MC_d <$?	$7.16 \le 7.19 \le 7.22$	$141.73 \le MCe < 241.73$	191.73	7.19
Medium-in-meat	$50 < MC_d < 100$	$5.61 \le 5.63 \le 5.65$	$91.73 < MCe < 141.73$	116.73	5.63
Low-in-meat	$0 < MC_d \le 50$	$4.65 \le 4.67 \le 4.70$	$41.73 < MC \le 91.73$	66.73	4.67
Vegetarian	0?	$3.79 \le 3.81 \le 3.83$	41.74	41.73	3.81
Vegan	0?	$2.83 \le 2.89 \le 2.94$	0	0	2.89

1. Sampling interval; 2. Daily meat consumption in [g]; 3. Daily dietary GHGE in [$kgCO_2e$];
4. Confidence interval; 5. Equivalent meat consumption in [g].

Tables 2: Estimation of GHGEs in 2013.

2013	MC_a in [kgRW] per capita[2]	MC_d in [gMW] per capita	$GHGE_{dd}$ by Eq.(1a) [kg-CO_2e]	$GHGE_{tn}$[4] [Mt-CO_2e]	Population by UNPD [000][6]	$GHGE_{td}$[7] [$kgCO_2e$]	Ra_{dt} (= $GHGE_{dd}$/ $GHGE_{td}$)
Argentina	84.6	213.2	8.30	431.6	42,538	27.80	0.298
Australia	92.5	233.2	8.61	514.8	23,270	60.61	0.142
Brazil	75.6	190.6	7.92	1,317.2	204,259	17.67	0.448
Canada	68.6	172.9	7.61	889.9	35,231	69.24	*0.110*
China	49.8	125.5	6.72	11,422.9	1,362,514	22.97	0.293
France	69.67[3]	175.6	7.66	362.0	63,845	15.54	0.493
Germany	69.01[3]	173.9	7.27	856.7	80,566	29.13	0.262
India	2.8	7.058	*4.11*	3,031.3	1,247,446	6.491	*0.633*
Indonesia	11.1	27.98	4.61	2,160.6	251,268	23.56	0.196
Italy	67.48[3]	170.1	7.56	386.5	59,771	17.74	0.426
Japan	34.6	87.21	5.94	1,360.8	126,985	29.36	0.202
Korea, S.	49.0	123.5	6.68	633.9	49,847	34.84	0.192
Mexico	46.5	117.2	6.56	742.0	123,740	16.43	0.399
Russia	60.6	152.7	7.24	2,076.0	143,367	39.67	0.183
Sa. Arabia	51.9	130.8	6.83	546.8	30,201	49.61	0.138
S. Africa	48.3	121.7	6.65	512.3	53,417	26.27	0.253
Turkey	28.1	70.8	5.58	343.6	76,224	12.35	0.452
UK	65.44[3]	164.9	7.47	534.1	63,956	23.26	0.321
USA	91.8	231.4	8.58	6,308.5[5]	317,136	54,50	0.158
Sum/Ave[1]	-	-	-	34,440.7	4387576	21.51	-
World	33.9	85.45	5.90	48,257.3	7181715	18.41	0.320

1. Based on 19 Countries of G20; 2. OECD [7];
3. FAO [11], data originally in dressed weight (DW);
4. CAIT [16]; 5. EPA [17]; 6. UNPD [18];
7. $GHGE_{tn}$ data in 5th column divided by 365 days and by population data in 6th column.

Tables 3: Estimation of total GHGEs in 2015.

2015	MC_a in [kgRW] per capita[1]	$GHGE_{dd}$ by Eq. (1d) [$kgCO_2e$]	$GHGE_{td}$ by Eq.(2) [$kgCO_2e$]	Population by UNPD[3] [000]	Predicted $GHGE_{tn}$ [$MtCO_2e$]	$GHGE_{tn}$ increase since 2013
Argentina	86.3	8.36	28.1	43,417	444	2.9%
Australia	92.5	8.61	60.6	23,969	530	3.0%
Brazil	75.2	7.90	17.6	207,848	1337	1.5%
Canada	68.1	7.58	69.0	35,940	905	1.7%
China	50.0	6.73	23.0	1,376,049	11550	1.1%
France	73.32[2]	7.82	15.9	64,395	373	2.8%
Germany	72.63[2]	7.78	29.7	80,689	876	2.2%
India	2.9	4.11	6.50	1,311,051	3111	2.6%
Indonesia	11.2	4.62	23.6	257,564	2217	2.6%
Italy	71.02[2]	7.71	18.1	59,798	395	2.2%
Japan	35.5	5.98	29.6	126,573	1367	0.46%
Korea, S.	52.4	6.85	35.7	50,293	655	3.4%
Mexico	47.1	6.58	16.5	127,017	765	3.1%
Russia	57.9	7.11	38.9	143,457	2040	*-1.7%*
Sa. Arabia	50.8	6.77	49.2	31,540	566	*3.6%*
S. Africa	47.8	6.62	26.2	54,490	520	1.6%
Turkey	28.9	5.63	12.4	78,666	357	4.0%
UK	68.86[2]	7.62	23.7	64,716	561	3.2%
USA	95.1	8.71	55.3	321,774	6491	2.9%
Sum/Ave	-	-	21.5	4,459,246	35073	1.8%
World	34.1	5.91	18.4	7,349,472	49453	2.5%

1. OECD [7] and FAO [11];
2. FAO [7] with a 5.24%-increase from 2013; 3. UNPD [18]

Tables 4: Estimation of dietary and total GHGEs of the world from 2015 to 2025.

year	MC_a[1] [kgRW]	$GHGE_{dd}$ by Eq. (1d) [$kgCO_2e$]	$GHGE_{td}$ by Eq.(2) [$kgCO_2e$]	Population by UN[2] [million]	Predicted $GHGE_{dn}$ [$MtCO_2e$]	Predicted $GHGE_{tn}$ [$MtCO_2e$]	Annual $GHGE_{tn}$ growth rate
2015	34.1	5.90845	18.4347	7349.472	15850	49453	1.253%
2016	34.3	5.91916	18.4681	7432.663	16058	50103	1.315%
2017	34.4	5.92452	18.4848	7515.284	16251	50705	1.203%
2018	34.6	5.93522	18.5182	7597.176	16458	51350	1.272%
2019	34.8	5.94590	18.5516	7678.175	16664	51991	1.248%
2020	34.8	5.94590	18.5516	7758.157	16837	52533	1.042%
2021	34.9	5.95124	18.5682	7837.029	17024	53115	1.107%
2022	34.9	5.95124	18.5682	7914.764	17192	53642	0.992%
2023	35.1	5.96192	18.6015	7991.397	17390	54258	1.149%
2024	35.2	5.96725	18.6182	8067.008	17570	54820	1.036%
2025	35.3	5.97258	18.6348	8141.661	17749	55377	1.016%

1. OECD [7]; 2. UNPD [18]

References

1. Heller MC, Keoleian GA."Greenhouse gas emission estimates of U.S. dietary choices and food loss". J Industrial Ecology. 2014; 19: 391-401.
2. Garnett T. "Cooking up a storm: food, greenhouse gas emissions and our changing climate". pp. 3 & 22, The Food and Climate Research Network. 2008.
3. Stehfest E, Bouwman L, van Vuuren DF, den Elzen MGJ, Eickhout B, Kabat P. (2009), Climate benefits of changing diet. Climatic Change. 2009; 95: 83-102.
4. Li H, Wu T, Wang X, Qi Y. The greenhouse gas footprint of China's food system: an analysis of recent trends and future scenarios. J Industrial Ecology. 2016; 20: 803-817.
5. Hawken P. Drawdown: The Most Comprehensive Plan Ever Proposed to Reverse Global Warming, Penguin, New York, NY. 2017; 218-221.
6. Chang YS, Jeon S."Using the experience curve model to project carbon dioxide emissions through 2040". Carbon Management. 2015; 6: 51-62.
7. OECD. Meat Consumption, OECD Data, Organisation for Economic Co-operation and Development (OECD). 2016.
8. USDA. Food Availability (Per Capita) Data System: Red Meat (Beef, Veal, Pork, Lamb, And Mutton). US Department of Agriculture (USDA). 2016.
9. Scarborough P, Appleby PN, Mizdrak A, Briggs ADM, Travis RC, Bradbury KE, et al. "Dietary greenhouse gas emissions of meat-eaters, fish-eaters, vegetarians and vegans in the UK". Climatic Change. 2014; 125: 179-192.
10. Tseng AA. "Reduction of greenhouse-gas emissions by Chinese Buddhists with vegetarian diets: a quantitative assessment". Contemporary Buddhism. 2017; 18: 89-107.
11. FAO. Food Supply - Livestock and Fish Primary Equivalent (Visualize Data), Food and Agriculture Organization of the United Nations. 2016.
12. Myfitnesspal. "Cooked meat weight vs raw meat weight". MyFitnessPal. 2016.
13. Bodybuilding. "Meat - raw weight vs cooked weight". Boise Idaho. 2016.
14. Showell BA, Williams JR, Duvall M, Howe JC, Patterson KY, Roseland JM, et al. USDA Table of Cooking Yields for Meat and Poultry. Beltsville Human Nutrition Research Center, Beltsville, Maryland. 2012.
15. Survivals of Jewels. "Raw vs. Cooked Weights". 2013.
16. CAIT. CAIT-Country Greenhouse Gas Emissions Data (Including Land-Use Change and Forestry). World Resources Institute. 2016.
17. EPA. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015. Rep. No. EPA 430-P-17-001, U.S. Environmental Protection Agency, Washington DC. 2017.
18. UNPD. "World Population Prospects: The 2015 Revision", Volume I: Comprehensive Tables, Rep. No. ST/ESA/SER.A/379, UN Population Division. 2015.
19. Tukker A, Jansen B. "Environmental impacts of products: A detailed review of studies." Journal of Industrial Ecology. 2006; 10: 159-182.
20. Garnett T. "Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)?". Food Policy. 2011; 36: 23-32.
21. Vermeulen SJ, Campbell BM, Ingram JSI. "Climate change and food systems," Annual Review of Environment and Resources. 2012; 37: 195-222.
22. Fiala N. "Meeting the demand: an estimation of potential future greenhouse gas emissions from meat production". Ecological Economics. 2008; 67: 412-419.
23. Friel S, Dangour AD, Garnett T, Lock K, Chalabi Z, Roberts I, et al. "Public health benefits of strategies to reduce greenhouse-gas emissions: food and agriculture". The Lancet. 2009; 374: 2016-2025.