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A Model for Adjusting Dietary Estimates of Greenhouse Gases Towards OECD Food Estimates

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Abstract

Research has shown that the meat-based portion of diets has a most serious effect related to greenhouse gases. Many studies rely on portion estimations, assuming a 'high-level' of daily meat consumption of 100 g and an average consumption of 2000 kcal. This meat estimate is less than one McDonalds quarter pounder. The Organization for Economic Co-Operation and Development (OECD) provides annual estimates of national meat consumption, where six nations average rank above the 200 g mark. We focus on EU and US, since there are both OECD data and dietary studies available for these higher-meat consumption nations. The OECD meat consumption for EU is at 189 g and US at 270 g daily. We prorate studies' research to assume the meat portion is equal to the OECD statistics and also prorate to a higher dietary consumption level of 2400 kcal. We accomplish this by providing a mathematical model and example results for 8 studies. These are analyzed for reasonableness by observing the greenhouse gases per kcal for meat and non-meat portions of diet. Our results provide an upper bound of the effects of meat consumption, not including fish, as well as to contrast existing studies using similar metrics. We found that both kcal estimates and meat consumption are strong drivers of GHG levels, and research should not be complacent with lower food estimates.

Keywords: greenhouse gas emissions; food consumption; vegetarian diet; sustainable diet; modeling & simulation.

1. Introduction

As climate change is becoming a greater concern, it becomes important to evaluate the major causes of greenhouse gases (GHG), in order to evaluate ways to reduce them. It is well-known that electricity, fuel for transportation and heating, and agriculture are major sources of climate change. Specifically, within agriculture the production of meat has been shown to be problematic to shifting atmospheric gasses such as methane and carbon dioxide. In this study, the research focuses on creating a model to evaluate changes in diets, by leveraging previous research, and determining how changes may affect greenhouse gas impact.

A number of studies have evaluated the CO2-equivalent (CO2e) GHG of various types of diets (high or low meat-eater, vegetarian and vegan) by estimating national consumption patterns (e.g., Baroni et al. 2007; González-García et al. 2018; Gerber et al. 2013). We noticed that many studies that provide estimates for dietary choices showed low meat consumption statistics: often a 'high' meat eater ate at or near 100 g of meat daily (e.g., Biesbroek et al. 2013; Gonzalez-Garcia et al. 2018; Scarborough et al. 2014). For portion estimation, consider that one McDonalds' quarter-pounder has 113 g of meat and is eaten in one meal. However, meat eaters tend to eat meat for 2-3 meals per day. Since a quarter pounder is a moderate amount of meat, 100g seems a low statistic for daily intake for a 'high' meat eater in a western nation. (McDonald's quarter-pounder is an excellent comparator, since it is sold worldwide.) This detail is important since meat consumption significantly impacts GHG estimates for diet.

Research has traditionally relied on reported portion sizes to estimate diet (e.g., Biesbroek et al. 2013; Soret et al. 2014; Sjörs et al. 2016; Scarborough et al. 2014), although sources indicate that people report eating less than they actually do by 20% or more (Berners-Lee et al. 2012). Greger (2019) writes that people on diets tend to report what they intended or wished to eat, and not what they actually ate. Our study uses as an alternative, national aggregate statistics as reported to the Organization for Economic Co-operation and Development (OECD).

Secondly, if portion sizes of meat is low, total food consumption is also likely low. Also, portion sizes vary due to changes in consumption over time. Table 1 shows many studies in wealthy countries have considered the recommended diet of 2000 kcal a day, while others study a more realistic diet of 2400-2700 kcal per day. The GHG estimates of a diet with too low an estimate of meat consumption and/or total consumption does not offer a realistic picture of the contribution of diet to GHG. A goal of our study is to proportion the results from studies of a recommended 2000 kcal/day to a more realistic and standard 2400 kcal/day.

Table 1. GHG study results for dietary consumption patterns

Nation	g/day meat	kcal/day	GHG kg/yr	GHG kg/day			Source
				Standard	Vegetarian	Vegan	
Denmark	205	2726	2029	3.42			(Saxe et al. 2013; Gonzalez-Garcia, 2018: S31)
Germany	103	2000	2051	5.62	4.27	2.63	(Meier and Christen, 2013; Gonzalez-Garcia 2018: S39, S42-43)
Netherlands	130	2537	2117	5.8	3.2	2.65	(Van de Kamp et al., 2018; Gonzalez-Garcia 2018: S44, S48, S50; van Dooren et al. 2014)
Sweden	110	2412	1898	5.2			(Röös et al. 2014)
UK	110	2000	2624	7.19	3.81	2.89	(Scarborough et al. 2014; Gonzalez-Garcia 2018: S12-S14)
UK	88	3548	2701	7.4			(Berners-Lee et al., 2012)
USA: 7th Day Adv.	64	2000	1113	3.05	2.16		(Soret et al. 2014)
USA	365	2000	4902	13.43			(Saez-Almendros et al. 2013; Gonzalez-Garcia 2018 S56)

Thirdly, food wastage is rarely accounted for, particularly when a recommended (2000 kcal) diet is considered. Gonzalez-Garcia et al.'s (2018) comprehensive study found that dietary calculations were not carried out consistently, and generally considered cultivation to farm-gate or to retail, but not to consumer. The UK Berners-Lee et al. (2012) study considers extraneous factors affecting GHG beyond estimated consumption with their estimate of 3548 daily kcal. Eshel and Martin (2005) calculate estimated food production at 3774 kcal/person/day in the U.S. Therefore, our upper estimate of 2400 kcal/day should be a very low estimate.

Fourthly, there may be sample error, when certain age groups or lifestyles are over or underrepresented, or different calculations result in grossly varying numbers. For example, in studying annual per capita GHG for a U.S. standard diet, one may contrast the Adventist Health Study 2 at 1113 Kg CO2e/year, Shrink That Footprint website at 2500 Kg CO2e/year, and Saez-Almendros et al. (2013) at 4902 Kg CO2e/year. These differ by over 4 times! One goal of our research is to enable adjusting for assumptions, analyze and attempt to explain differences, and provide a mechanism where projections can be made as diet changes.

The OECD, with its 36 member nations, provides up-to-date estimates of meat consumption for member nations within a database (OECD, 2019). This database indicates that only 10 of 34 countries have average daily 'retail' meat consumption lower than 100 g while 6 countries report meat consumption over 200 g per day. Many research studies (see Table 1) estimated meat consumption lower than that reported by the OECD for retail consumption. This means that our measure of 'high' meat consumption should be adjusted. We use a combination of OECD and research data to provide higher (and arguably more realistic) estimates for national dietary GHG data.

The OECD database provides statistics per nation, either as tons of 'carcass weight', or as 'retail weight per capita'. We work with the per capita estimates of retail weight, which is calculated as 70-88% of carcass weight. OECD statistics may average higher, because stores do not sell all of their meat and consumers may discard or chop off parts of purchased meat. However, for GHG purposes, it does not matter if the meat was consumed or discarded. The UK Berners-Lee et al. (2012) study considers extraneous factors affecting GHG beyond estimated consumption, but offers an adjustment only to their study. OECD statistics provides a high-end nationally-provided statistic (as opposed to individual dietary estimates) as a dietary basis for GHG effects. This counters study results, which appear low.

Table 1 illustrates data from the studies that we will be working with, showing annual CO2e (GHG) estimated in kg/day and kg/year, and the corresponding meat consumption. These studies have estimated local diets and we project their results with OECD member nation statistics and contrast them with each other. Our analytic model enables testing of different food amounts, in order to estimate the impact of changes in diet on greenhouse gasses. In this study we enlarge the meat portion of the diet to OECD statistics and correspondingly reduce the nonmeat portion of the diet. We assume the original paper's distribution of meat accords with OECD statistics (although this is not necessarily true). We calculate results for 2000 and 2400 kcal diets. We are not aware of other modeling studies that project from existing studies. (Computer studies tend to work with user interfaces to collect and display GHG emissions, e.g., Ganglbauer et al. 2012, 2013.)

In section two we detail our analytic model. In section three we provide results and analysis, and finally conclude in section four.

2. Method

OECD (2019) provides statistics by nation for the 'retail consumption' each of beef, pig, poultry, sheep, in Kg. We calculate the greenhouse gases (GHG) or CO2e for each amount of meat from UN FAO data from the source: "Tackling Climate Change through Livestock" (Gerber et al. 2013). It provides multiple numbers per each of beef, pig, poultry and sheep, considering grazing, mixed and/or intensive types of farming. Grazing farming generally produces more GHG (Gerber et al. 2013). We selected the total (or averaged) emission intensity considering all forms of farming. This favors mixed/intensive farming, which is more commonly used. Using these UN and OECD sources, we calculate the average meat consumption and resulting GHG per person on a national basis, where 'beef' equals the kg of beef for nation x, etc. Equation (1) provides the annual average production per person of GHG for just the meat consumption (of beef, pig, poultry and sheep) for a particular nation:

$$GhgMeat = 46.2 * beef + 6.1 * pig + 5.4 * poultry + 23.8 * sheep \quad (1)$$

We took average kcal per meat type from www.nutritionix.com. Commonly statistics are provided as kcal per 100 grams consumed. The kcal of this consumption (in grams/day) are calculated using average kcal statistics for each meat, as follows:

$$KcalMeat = \frac{[(291 * beef + 220 * pig + 238 * poultry + 294 * sheep) * 10]}{365} \quad (2)$$

where kcal/100 grams are multiplied by 10 to obtain kcal per kg that the meat is measured in. These three statistics are generated solely from OECD and UN data, independent of the previous research. The next calculations are derived from various research studies in relation to this OECD-UN data.

The first question is what is the difference in meat consumption in published studies versus OECD-UN statistics? We calculate a ratio of the published research study's estimated meat consumed divided by the OECD-provided data, adjusting for reporting in grams or Kg:

$$Ratio = \frac{MeatCons(sudy)}{MeatCons(OECD)} \quad (3)$$

This ratio demonstrates a delta in studies' GHG results. However, we recognize that we introduce an error in that MeatConsumed(OECD) does not include fish.

We next consider the effects on GHG according to the OECD-UN data. To accomplish this, we need to separate out the kcal and GHG estimates for the meat versus non-meat portion of a study's diet. We subtract out the study's estimated GHG for meat consumption and replace it with the OECD-UN's estimated GHG for meat consumed. However, we need to prorate kcal, since we want to assume no change in kcal/day. (After all, the study authors assumed a particular CO2e based on the kcal.) The data we collected from research studies include (1) the meat consumption per day, (2) daily kcal, and (3) the CO2e per day or year, per person. We estimate the CO2e attributed to meat as the OECD-UN GHG statistics times the ratio of study-to-OECD-UN meat consumption:

$$GhgMeat(study) = GhgMeat(OECD) * Ratio \quad (4)$$

The Kcal attributed to meat are proportioned similarly. An error may result, since we are assuming that the proportions of the various meats is the same in the research versus OECD reporting. We can now proportion the amount of kcal and GHG to non-meat portions of the diet:

$$KcalNonMeat(study) = Kcal(study) - KcalMeat(study) \quad (5)$$

The next step is to proportion the full OECD-UN estimate for meat in the diet. Here we calculate the additional (extra) meat estimated by the OECD data:

$$XMeat = MeatCons(OECD) - MeatCons(study) \quad (6)$$

Then we calculate the kcal and GHG for the additional (extra) meat using OECD-UN totals, where these totals are in the equivalent measuring units (e.g, g/day or Kg/year):

$$KcalXMeat = XMeat * \frac{KcalMeat(OECD)}{MeatCons(OECD)} \quad (7)$$

$$GhgXMeat = XMeat * \frac{GhgMeat(OECD)}{MeatCons(OECD)} \quad (8)$$

We must then subtract out the reduced proportion of non-meat (NM) diet for an equivalent amount of kcal:

$$KcalLessNM = KcalNonMeat(study) - KcalXMeat \quad (9)$$

$$GhgLessNM = GhgNonMeat(study) * \frac{KcalLessNM}{KcalNonMeat(study)} \quad (10)$$

Finally, we can determine the end result of the increased rate of meat consumption, providing new CO2e statistics by summing the meat and non-meat parts of the diet.

An important statistic is the CO2e estimate per kcal for meat and non-meat, which helps to determine the efficiency of a portion of a diet (e.g.):

$$\frac{Ghg(Non)Meat}{kcal} = \frac{Ghg(Non)Meat(study)}{Kcal(Non)Meat(study)} \quad (11)$$

3. Results and Analysis

We reviewed calculations from 8 studies for nations known for high meat consumption for which OECD data and dietary studies exist: U.S.A. and European Union. OECD statistics are not available for EU member states. In a special case of Sweden and Denmark, OECD statistics were available for neighboring, culturally-similar Norway. So those two studies are projected using both sets of OECD statistics.

Figure 1 shows CO2e data in graph form as original paper data (blue bar) and revised with OECD-changed meat consumption for a fixed 2000 (red bar) and 2400 kcal diet (gray bar). The names of the nations include the original kcal associated with the blue bar results. Denmark (DK) and Sweden are shown using both OECD EU and Norway (NW) data.

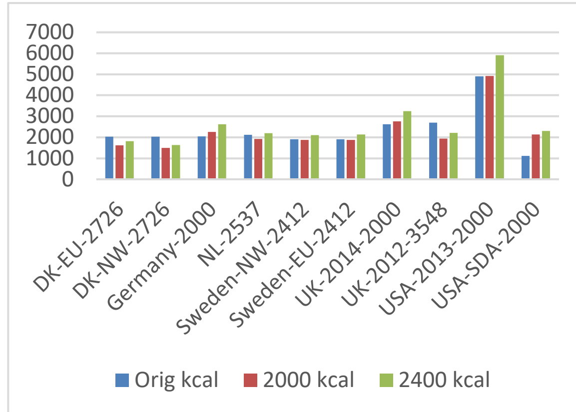

Figure 1: GHG Emissions for Original vs. 2000 vs. 2400 kcal.

Table 2. A comparison of 8 studies from US and EU

	Paper statistics			Derived OECD		Revised Calories 2000			Revised calories >=2400		
Study	g/day meat	kcal/day	Ghg kg/yr	g/day meat	Ghg kg/yr	kcal/day	Ghg g/day	Ghg kg/yr	kcal/day	Ghg g/day	Ghg kg/yr
DK (Saxe et al. 2013) (EU)	205	2726	2029	189	873	2000	4.45	1623	2726	5.41	1975
DK (Saxe et al. 2013) (NW)	205	2726	2029	153	948	2000	4.12	1503	2726	4.80	1751
Germany (Meier & Christen 2013) (EU)	103	2000	2051	189	873	2000	6.20	2263	2400	7.19	2623
NL (van de Kamp et al. 2018) (EU)	130	2537	2117	189	873	2000	5.28	1927	2537	6.28	2293
Sweden (Röös et al. 2014) (NW)	110	2412	1902	153	948	2000	5.13	1872	2412	5.77	2107
Sweden (Röös et al. 2014) (EU)	110	2412	1902	189	873	2000	5.14	1876	2412	5.87	2144
UK (Scarborough et al. 2014) (EU)	110	2000	2624	189	873	2000	7.56	2758	2400	8.89	3246
UK (Berners-Lee et al., 2012) (EU)	88	3548	2701	189	873	2000	5.31	1937	3548	8.22	3001
USA (Saez-Almendros et al. 2013) (USA)	365	2000	4902	270	1613	2000	13.48	4919	2400	16.20	5912
USA SDA (Soret et al. 2014)	64	2000	1113	270	1613	2000	5.86	2141	2400	6.30	2299

Table 2 illustrates the results for the eight studies, contrasting the original study with the OECD-changed meat consumption adjusting to the paper's kcal value. In the first columns of Table 2 we show the paper's original statistics. The second set of columns revise the meat portion using OECD-UN statistics. The third and fourth sets of columns show the revised numbers using OECD-changed meat consumption, assuming either the 2000 kcal/day and 2400 kcal/day, unless the original paper was calculated above 2400 kcal, in which case we kept their original kcal/day statistic. The portion of meat eaten in both Revised Calories columns are consistent with the OECD meat-consumption data.

3.1. Effectiveness of Numbers

One can argue that the OECD-UN meat consumption numbers provide national aggregated statistics and thus a more realistic perspective for calculating the GHG of diets than dietary estimates. If the OECD-UN meat consumption numbers are more accurate, then the determination is which kcal/day should be used: the recommended 2000 kcal/day; possibly a more reasonable estimate of 2400 kcal/day (or more); or a value that considers food discard at the store and home. We argue that the higher values offer a more realistic picture of generated GHG.

The E.U. is a series of nations and cultures with different eating styles, and a couple of OECD statistics may be insufficient to estimate them accurately. However, countries with reputations for low meat, such as Italy's Mediterranean diet, has tripled its meat consumption in the last 50 years and now Italy ranks at the 'high' meat consumption of 113 g/day (Farchi et al., 2017), which is commensurate with other EU dietary survey studies. Secondly, OECD numbers are estimates and while previous research arguably provided low numbers, these numbers may provide (hopefully) a reasonable upper bound average. Thirdly, we introduce next a mathematical approach to investigate the reasonableness of the results.

One way to determine reasonableness is to look at the CO2e/kcal. We calculated the CO2e/kcal for meat and non-meat portions of the diet. The meat CO2e/kcal is calculated from OECD data for the nation, then the remainder of the CO2e for kcal is calculated based on the non-meat portion. One possible problem is if the non-meat number is abnormally high or low, compared to other studies. An example is the U.S. (Saez-Almendros et al. 2013) study which has a high non-meat portion of the diet. Another problem may be if the non-meat portion of a meat-eater diets is more efficient than a vegetarian or vegan diet. An example of this is the second Denmark study, projected from a Norwegian OECD diet, which has a non-meat diet well below any estimates for a vegan diet. Therefore, Table 3 can display gross errors in assumptions.

Gross errors arise due to a mis-estimation of the portions of meat consumption between the original study and revised OECD numbers. The higher error in the (Saez-Almendros et al. 2013) numbers may arise because beef is estimated larger in the study numbers than OECD-reported. Scarborough et al. (2014) UK study likely has a higher average CO2e meat consumption than the Berners-Lee et al. (2012) UK study. The lower error in the Danish study may arise because Denmark likely eats more EU-like (with pork and chicken) than Norway (beef and not-included sea food).

We also consider why the meat-eater's non-meat GHG/kcal value may be higher than the vegetarian. An explanation may be that it is due to the addition of fish, or because of higher rates of consumption of high-GHG beef, lamb, and cheese. In Table 3, Scarborough et al. (2014) UK study likely considers a higher than average CO2e meat consumption in contrast to the Mediterranean EU diet, with a likely lower than average EU meat consumption.

There is a question of appropriate distribution for the various meats, since fish is not included in the OECD data. Coastal EU nations likely have a high rate of fish consumption, and potentially lower rates of other meats. This model does forgive some error, since Scarborough et al.'s (2014) UK study rates the GHG of chicken and seafood similarly, at 5.4 kg CO2e/kg, with pig only slightly higher at 7.9. Therefore, quantities of poultry and fish can be swapped. Pig can be swapped with only slightly higher error.

Table 3: Comparing GHG/kcal for various studies

	Meat portion	**Non-meat portion**	**Vegetarian**	**Vegan**
Study	ghg/cal	ghg/cal	ghg/cal	ghg/cal
DK (Saxe et al. 2013) (EU)	5.28	1.33		
DK (Saxe et al. 2013) (NW)	6.82	0.94		
Germany (Meier & Christen 2013) (EU)	5.28	2.46	2.14	1.32
NL (van de Kamp et al. 2018)	5.28	1.87		
NL (van Dooren et al. 2014)			1.60	1.33
Sweden (Röös et al. 2015) (NW)	6.82	1.56		
Sweden (Röös et al. 2015) (EU)	5.28	1.78		
UK (Scarborough et al. 2014) (EU)	5.28	3.34	1.91	1.45
UK (Berners-Lee et al., 2012) (EU)	5.28	1.88		
USA (Rose et al. 2019)	6.61	3.79		
USA (Saez-Almendros et al. 2013)	6.61	6.80		
USA SDA (Soret et al. 2014)	6.61	1.09	1.08	
US (Heller and Keoleian 2014)			1.20	0.85

3.2. Comparison of Diets

Of the studies we investigated, half of them assumed a kcal of 2000 while the other half estimated above our 2400 kcal ranging between 2412 and 3548. Therefore, our estimate of 2400 kcal (likely more reasonable than 2000 kcal) appears low. Two studies assumed higher meat consumption than OECD estimates: Denmark's (Saxe et al. 2013) and USA's (Saez-Almendros et al. 2013) study. The remainder estimated meat consumption low relative to OECD. Since Mediterranean nations were not evaluated, some of these studies should rank above the EU average meat consumption.

Our results show that the GHG is affected both by meat and kcal consumption. Denmark's (Saxe et al. 2013) study is the only study that estimated both higher meat and kcal consumption than this study, and in this one case, our CO2e calculations are lower than theirs.

For the remainder seven studies we estimate higher CO2e results when kcal is matched. One study, USA (Saez-Almendros et al. 2013) assumed a higher meat consumption, but lower kcal. We lowered the meat consumption and raised kcal, and our calculated GHG are higher. Five studies assumed lower meat consumption, and when kcal was matched or raised, GHG estimates rose.

Figure 1 shows a slightly different story, because in this case we matched all studies to a maximum 2400 kcal. Here two studies' CO2e results dropped, including Denmark and UK (Berners-Lee et al., 2012), basically because both studies estimated kcal at 2726 or higher. Of the remaining studies, CO2e results rose slightly to considerably, even when kcal fell. The average CO2e estimate is 2619 kg/year, but the range varies wildly between 1817 and 3246 for the EU, and 2300 and 5912 for the US. Since we hoped for a consolidation of results, we plan to further investigate these differences.

Contrasting vegetarian and vegan diets, it is possible to simply use the GHG/kcal statistic to linearly project to 2400 kcal. Vegetarian diets average 1360 kg CO2e/year, ranging between 946 and 1870 kg/year. Vegan diets average 998 kg CO2e/year, ranging between 745 and 1266 kg/year. Thus, meat consumption at 2400 kcal results in about 2.5 tons, whereas vegetarian ranks at 1 1/3 ton and vegan at slightly less than 1 ton.

4. Conclusion

This research leverages previous studies by using an innovative modeling approach to model GHG emissions of dietary consumption. We show it is possible to change components of the diet and recalculate GHG effects, and to investigate whether proposed changes are reasonable by evaluating the GHG/kcal for the non-affected portion of the diet. This is important, because it is helpful to understand the variances in results between studies, but also because the model enables the calculation of theoretical or actual variances in dietary choices.

Many studies rely on dietary estimates, which can underreport consumption. This new model offers another way of calculating consumption, via OECD statistics. While OECD estimates may overestimate meat consumption, it may be the most accurate data available related to retail meat allocation per capita, which is a strong driver of GHG. However, it can be argued that even these greater estimates may be low because data on fish consumption is not readily available. This modeling also helps in investigating differences between studies.

Our results found that both kcal estimates and meat consumption are strong drivers of GHG levels, and research should not be complacent with lower food estimates.

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