7 Contributions to Global Climate Change: A Cross-National Analysis of Greenhouse Gas Emissions from Meat Production

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Global climate change is already having measurable effects on sea level and global temperature averages (IPCC 2013), and animal agriculture is a substantial source of the greenhouse gas (GHG) emissions contributing to climate change. In 2015 animal agriculture contributed 65 percent of the total global emissions from agriculture and 7 percent of total GHG emissions globally (author calculations using FAO data and global data from Olivier, Schure, and Peters [2017]). Agriculture as a whole is responsible for about 11 percent of world GHG emissions. Although neither agriculture nor animal agriculture is the largest producer of GHG emissions, both are significant sources, and global meat production has increased (see chapter 1).

While there are many arguments against eating meat, it seems unrealistic to expect that the entire world population will give up eating meat in the near future (see chapters 8 and 9). Meat eating has strong cultural traditions, is an important source of fat and protein for many people living in marginal environments (grasslands, etc.), and is also a by-product of dairy, fiber production, and draft power. If we take as a given that meat consumption will continue at some level (not necessarily the current one), then the question is how and where should this meat be produced? Reducing the amount of GHG emissions that are produced by meat production is a step toward more sustainably feeding the world population.

GHG emissions from meat production are a particularly important type of environmental impact to consider from a social and environmental justice standpoint because the effects are ultimately felt on a global scale through global climate change. However, the effects of climate change are not being felt evenly (Hallegatte et al. 2016), and, as is the case with other sources of GHG emissions (like from fossil fuels), the places producing the most GHG emissions from meat production tend to be the same places that will be least affected by climate change or that have the most resources available to adapt to it, or both (see chapter 1).

This chapter considers the total GHG emissions and emissions intensities of beef, pork, and chicken production across countries and over time. What factors drive total emissions and emissions intensities? What is the relationship between total emissions and emissions intensities? Geographically, where are the most emissions coming from and where is the most GHG-efficient meat production? Does more intensive meat production produce fewer GHG emissions? GHG efficiency is one of several kinds of efficiency that should be considered when assessing the sustainability of meat production, but GHG efficiency has the greatest direct implications for global climate change.

Animal Agriculture and GHG Emissions

The main types of GHG emissions from animals are methane (CH_4), which has a global warming potential (GWP) that is twenty-five times that of CO_2, and nitrous oxide (N_2O), which has a GWP that is nearly three hundred times that of CO_2. These emissions are the result of enteric fermentation (i.e., a key process of ruminant[1] digestion) and from manure, which is either collected in pits or lagoons (e.g., "manure management systems"), left to decompose on a pasture, or applied to soils as a fertilizer. Animal diet (and more technical chemical manipulation of the diet) can influence emissions from enteric fermentation, with greater roughage/less nutrient-dense foods in the diet generating more GHG emissions than diets with higher amounts of concentrated feed (Macleod et al. 2013, xix). The emissions from manure management practices vary depending on their specifics and the temperature of the location, as do the emissions from manure left on pasture and applied to soils.

Worldwide, total GHG emissions from cattle, pigs, and chickens combined increased by 66 percent from 1961 to 2015. However, this increase in emissions has not been even across the globe. Emissions over the past fifteen years have increased the most in South America and Africa, and South America has been the top-emitting continent since 2001 when its emissions surpassed those of Asia. In 2015, the top three continents for total meat animal emissions were South America (558,000 gigagrams [Gg]

CO_2eq—GHG emissions converted into equivalent about of CO_2 based on their GWP), Asia (480,000 Gg CO_2eq), and Africa (297,000 Gg CO_2eq).

From 1961 to 2015, missions from meat animals increased from all sources. During this period, emissions from enteric fermentation increased 58 percent, emissions from manure left on pasture increased 92 percent, and emissions from manure management and from manure applied to soil increased 68 percent and 66 percent, respectively. These increases are not really surprising as meat production has increased during this period as discussed in the introduction and shown in figure 1.2. The portions of total emissions from each source have been relatively stable over time.[2] In 2015, the majority of total GHG emissions from meat animals came from enteric fermentation (60 percent), 23 percent came from manure left on pasture, 12 percent from manure management, and 5 percent from manure applied to soils.

The top graph in figure 7.1 shows that total GHG emissions from cows, pigs, and chickens each increased significantly from 1961 to 2015, as the global meat industry expanded. The overall increase in emissions during this time period has been greatest from chickens (a 683 percent increase), while emissions from pork have increased by 107 percent and emissions from beef have increased by 58 percent.

Overall, beef cattle produce the most total emissions (note the different scale for beef in figure 7.1), largely as a result of their physiology—they are large, relatively slow-growing ruminants and thus per animal produce the most GHGs (Gerber et al. 2015), even though beef production and the number of cattle slaughtered is comparatively low (see figures 1.2 and 1.3). Pigs produce the second-most emissions, followed by chickens. Of particular note, pork production in 2015 was about 25 percent greater than that of chicken (see figure 1.2), but pigs produced about three times more emissions than did chickens. This is also largely a result of size and physiological difference between pigs and chickens and the differences that result in growth rate, kind of food consumed, and digestive process and the GHGs that result (Gerber et al. 2015).

Emissions intensity (EI) is the GHG emissions produced divided by the amount of meat produced. Consistent with the total emissions for each type of meat, beef has the highest EI, then pork, and then chicken. In 2015 a globally average kg of pork produced more than twice as much CO_2eq GHGs than chicken, and a kg of beef produced about forty-four times as

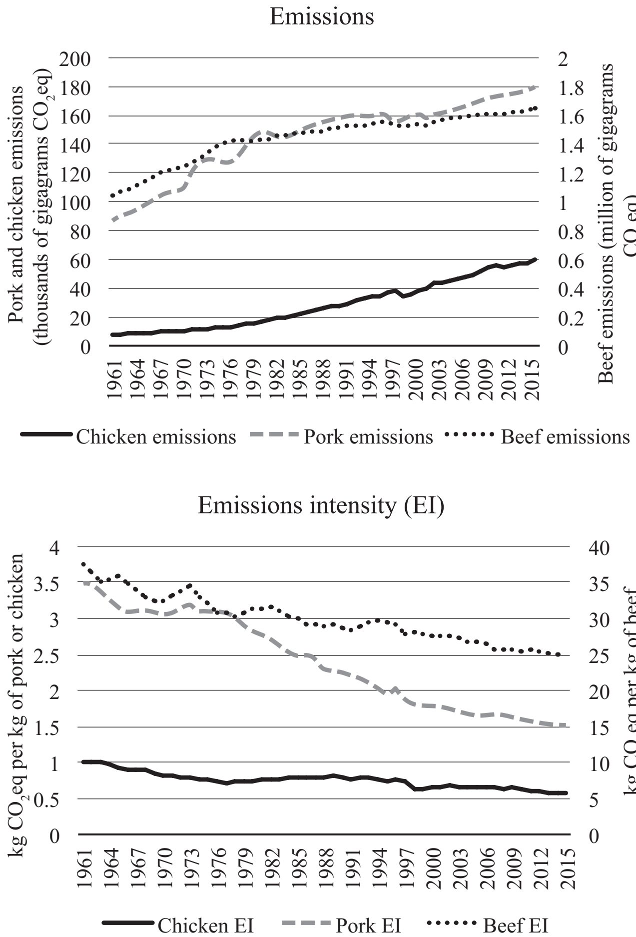

Figure 7.1

Total GHG emissions and emissions intensities (EI) for chicken, pork, and beef, 1961–2015

Source: FAO 2019.

many emissions as chicken and about sixteen times as many as pork (note the different scale for beef in figure 7.1). Not only does EI allow for comparisons between the emissions from different types of meat, it also lets us make some comparisons between places in terms of GHG efficiency.[3]

The bottom graph in figure 7.1 shows that the global EI for beef, pork, and chicken has decreased over time. While EIs have decreased over time across all continents as well (and most dramatically in Asia[4]), which would seem to be a good thing, much of this efficiency gain in GHG emissions has been achieved by raising animals more intensively, meaning more animals in less space, and getting them to grow as quickly as possible. This model of animal production creates concerns for animal welfare and environmental quality in the surrounding area due to dust, odors, and large volumes of animal wastes, as well as the potential for disease spread (and greater use of pharmaceuticals to control disease). This type of efficiency is also made possible by growing crops (like corn/maize and soybeans) specifically for animal feed, which creates other environmental concerns and GHG emissions that are not included in meat GHG emissions measures.

Figure 7.2 shows the 2011–2015 average beef emissions, beef production, number of cattle slaughtered, and EIs by continent and is ordered by total beef emissions. This graph and the ones like it for pork and chicken highlight the relationships among the graph components, particularly between meat emissions, production, and EI. Total emissions are the product of the GHG efficiency of cattle production (not including feed production) and the amount of meat produced. Meat production in turn is the product of the number of animals slaughtered and the size of the animal in terms of how much meat each one yields. Thus a continent or country that is highly GHG efficient in meat production (i.e., that has a low EI) can still emit a very large amount of total GHGs due to very high production, while a GHG inefficient country (i.e., that has a high EI) can emit very low total GHGs due to having very little beef production. The FAO calculation of GHG emissions from each type of animal from each source is calculated using an emissions factor multiplied by the number of animals of that type. The emissions factors include the effects of general differences in feed quality (which influences how much methane is produced during digestion), and regional climate (which influences the GHG emissions from manure sources).

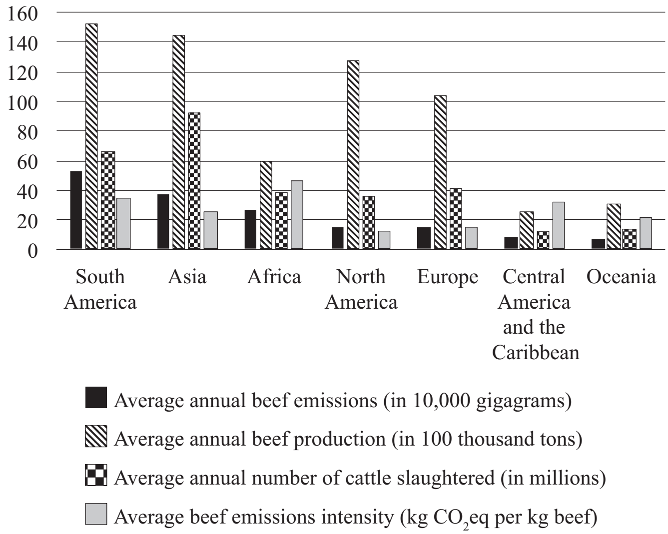

Figure 7.2
Beef emissions, production, and emissions intensities by continent, 2011–2015 averages
Source: FAO 2019.

Figure 7.2 shows that South America produces the largest amount of beef and the most beef emissions, followed by Asia. North America and Europe produce the third and fourth most beef and the fourth and fifth most beef emissions. These top beef-producing continents were not surprisingly home to the top beef-producing countries in 2014: The United States (11.5 MMT[5]), Brazil (9.7 MMT), the European Union (7.4 MMT), and China (6.9 MMT). These four countries also produced the most individual beef emissions, but in a different order from their beef production due to differences in their beef EIs: Brazil produced 316,000 Gg CO_2eq (60 percent of the beef emissions from South America), China produced 161,000 Gg CO_2eq (44 percent of Asia's beef emissions), the United States produced 134,000 Gg CO_2eq (88 percent of North America's beef emissions), and the EU produced 120,000 Gg CO_2eq (77 percent of Europe's beef emissions). Altogether, these four countries produced 42 percent of the world's beef, and 37 percent of the world's beef emissions. Brazil, China, and the United States are also the homes of the three largest meat processing firms in the world: JBS, WH Group, and Tyson (see chapter 2).

Figure 7.3 shows that pork production and emissions are highest in Asia, Europe, and North America. Within these continents, China, the EU, and the United States are the top producers of both pork and emissions. In 2014, China produced 55.4 MMT of pork and 56,000 Gg CO_2eq (74 percent of Asia's pork emissions), the EU produced 22.6 MMT of pork and 37,000 Gg CO_2eq (83 percent of Europe's pork emissions), and the United States produced 10.4 MMT of pork and 21,000 Gg CO_2eq (84 percent of North America's pork emissions). While these three countries have relatively low pork EIs, the sheer scale of their pork production results in them all together producing 75 percent of the world's pork, and 64 percent of the world's GHG emissions from pork. The high pork production and emissions from China clearly shows the result of China's pork boom described in chapter 4.

Figure 7.4 shows that Asia is the top-producing region for both chicken and chicken emissions, followed by South America, North America, and Europe. Similar to beef, the top meat-producing counties in 2014 were the United States (17.7 MMT), China (12.8 MMT), and Brazil (12.5 MMT).

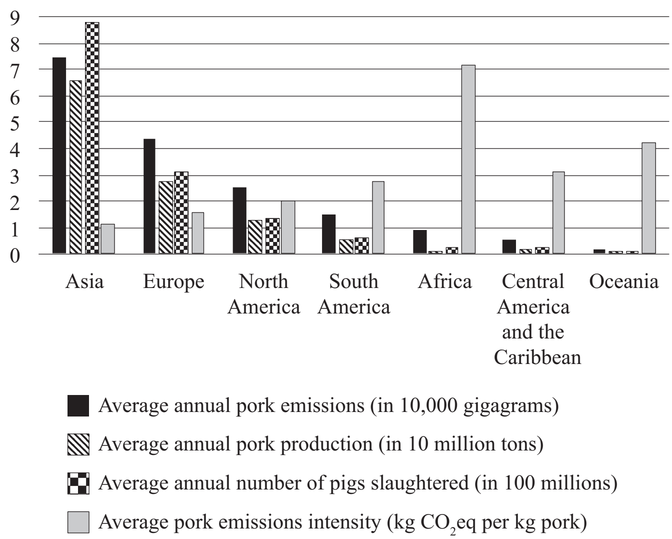

Figure 7.3
Pork emissions, production, and emissions intensities by continent, 2011–2015 averages
Source: FAO 2019.

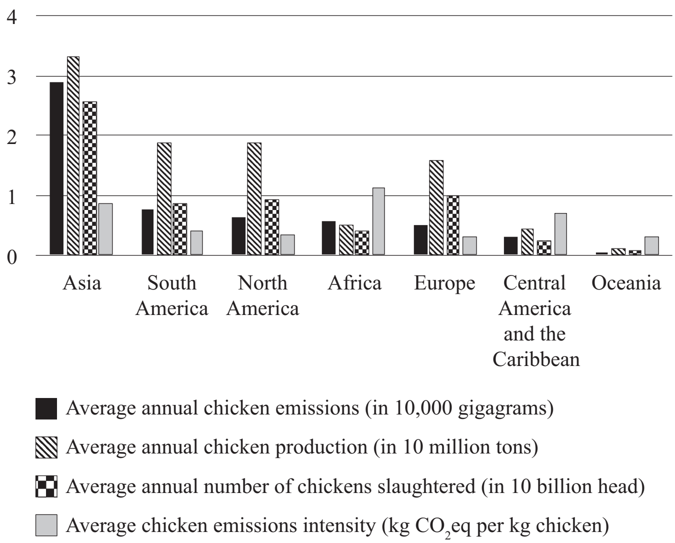

Figure 7.4
Chicken emissions, production, and emissions intensities by continent, 2011–2015 averages
Source: FAO 2019.

However, the countries with the most chicken emissions in 2014 were China (8,000 Gg CO_2eq, which is 24 percent of Asia's chicken emissions), Indonesia (7,000 Gg CO_2eq, which is 21 percent of Asia's chicken emissions), the United States (6,000 Gg CO_2eq, which is 65 percent of North America's chicken emissions), Brazil (4,000 Gg CO_2eq, which is 46 percent of South America's chicken emissions), Iran (4,000 Gg CO_2eq, which is 10 percent of Asia's chicken emissions), and the EU (3,000 Gg CO_2eq, which is 32 percent of Europe's chicken emissions).[6] These six countries produced 58 percent of the world's chicken meat and 56 percent of chicken emissions in 2014.

The high emissions from Indonesia and Iran are the result of relatively high chicken production (they were 10 and 9 respectively in chicken production in 2014) along with high EIs: Indonesia's EI was 3.6 kg CO_2eq per kg of chicken, while Iran's was 1.7. In contrast, China's EI was 0.6, while the United States and Brazil had chicken EIs of 0.3. A similar situation can be seen at the continent level for beef (figure 7.2) where Africa's high beef EI puts it third highest for beef emissions even though it is fifth in beef production. When meat production is very low, even a very high EI can result in low emissions, such as can be easily seen for pork production in Africa, Central America and the Caribbean, and Oceania (figure 7.3).

While the preceding discussion is highly informative, it does not tell us what it is about these regions and countries that make them more or less GHG efficient in producing different kinds of meat. EIs have gone down over time, but why? Is it the result of the rise of high-intensity meat production? In the following section I use a statistical analysis to shed some light on this question and help us to better understand what characteristics are related to high and low emissions intensities.

Statistical Analysis Approach and Design

I combine two approaches for this analysis of what drives the GHG EIs from meat animals. First, I draw on the insights of the political economy of agriculture from the sociology of agriculture literature. Second, I use the STIRPAT model of environmental impact from the environmental sociology literature (Dietz and Rosa 1997; York, Rosa, and Dietz 2003a,b).

The political economy of agriculture literature focuses on the shift toward more intensive production—intensive both in the use of space and in use of capital—and producer and consumer resistance to this shift through alternative food networks and marketing strategies (see, for example, Ilbery and Maye 2005a,b; Little et al. 2012; Watts, Ilbery, and Maye 2005). STIRPAT stands for "stochastic impacts by regression on population, affluence and technology" and represents environmental impacts (I) as being the result of the combined effects of population (P), affluence (A) and technology (T) in a form that can be implemented with a regression analysis (Dietz and Rosa 1997; York, Rosa, and Dietz 2003a,b).

While the sociology of agriculture has long worked from a place of concern over the environmental and social sustainability of modern agriculture (see Hinrichs and Welsh 2003 as a good example), it has tended to give much more explicit attention to the social arrangements of agriculture production and food systems. Combining a political economy view of technology and production practices with the STIRPAT model provides both a conceptual foundation and an empirical approach for the statistical analysis.

In the following statistical model, I use EIs as the outcome variable, in this case representing the unit, rather than the overall, environmental impact (I) of meat production, for each of three types of meat: beef, pork, and chicken.[7] The independent variables of greatest interest in this analysis are animal density, production intensity, manure management, and carcass yield (see tables 7.1 and 7.2 for variable definitions). These first three variables are acting as measures of the extensiveness vs intensiveness of the methods of animal production. The manure management percent variable is the most direct measure available of animal production practices since this approximates the proportion of the meat animal population that is being kept in a confinement situation (i.e., intensive production). High values on all three of these measures indicate more intensive meat animal production, such as confined animal feeding operations (CAFOs) and possibly accompanying higher degrees of corporate concentration (see chapter 2), while lower measures suggest more extensive production practices. Carcass yield is expected to be an important measure when it comes to EIs, because it is also a measure of production efficiency. The rest of the variables are controlling for general national and agricultural context, and climate and culture differences that cannot be included in the analysis directly due to lack of data.[8]

Results and Discussion

The analysis results are shown in table 7.3.[9] The beef analysis is the best in that it explains the most variation in the data at 82 percent (R-squared value), while the pork and chicken analyses explain 44 percent and 80 percent of the variation, respectively. The question we want to answer is: What variables are related to a country having higher or lower meat EIs, all else being equal? Does greater production intensity reduce the EI through more GHG-efficient meat production? Remember that the EI measure does not include emissions from things like feed production or transportation. In considering the results of the analysis, the sign of the coefficient matters: a positive coefficient indicates that as the independent variable increases so does EI, while a negative coefficient indicates that an increase in the input variable is associated with a reduction in EI. The numerical value of the coefficient indicates the relative size of the effect on EI.

Table 7.1

Variable definitions for emissions intensity analyses of for beef, pork, and chicken

Variable name	Beef variable descriptions	Pork variable descriptions	Chicken variable descriptions
Emissions intensity	kg of emissions (converted to CO_2 equivalence) per 100 kg of beef. Logged.	kg of emissions (converted to CO_2 equivalence) per 100 kg of pork. Logged.	kg of emissions (converted to CO_2 equivalence) per 100 kg of chicken meat. Logged.
Animal density	Number of nondairy cattle per 1,000 hectares of agricultural land. Logged.	Number of market swine per 1,000 hectares of agricultural land. Logged.	Number of broiler chickens per 1,000 hectares of agricultural land. Logged.
Production intensity	Nondairy cattle as a percentage of total cattle. Logged.	Omitted from analysis due to lack of variation.	Broiler chickens as a percentage of total chickens. Logged.
Manure management percent	Percent of nondairy cattle emissions that are from manure management. Logged.	Percent of market swine emissions that are from manure management. Logged.	Percent of broiler chicken emissions that are from manure management. Logged.
Carcass yield	Average beef carcass weight in hectograms per animal slaughtered. Logged.	Average pig carcass weight in hectograms per animal slaughtered. Logged.	Average chicken carcass weight in 0.1 grams per animal slaughtered. Logged.
Animal number	Number of nondairy cattle. Logged.	Number of market swine. Logged.	Number of broiler chickens. Logged.
GDP per capita	Gross domestic product per capita in constant 2011 international dollars. Logged.		
Percent agricultural land	Agricultural land area as a percentage of total country land area. Logged.		
Percent arable land	Arable land area as a percentage of total agricultural land area. Logged.		
Island	Is the country an island? 1 = yes, 0 = no		

Table 7.2

Continents, regions, and countries used in analysis (consistent with FAO regions)

Africa	
Eastern Africa	Burundi, Comoros[c], Djibouti[bc], Eritrea[c], Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Mozambique, Rwanda, Seychelles, Uganda, United Republic of Tanzania, Zambia, Zimbabwe
Middle Africa	Cameroon, Central African Republic, Chad, Congo, Democratic Republic of the Congo, Equatorial Guinea, Gabon, Sao Tome and Principe
Northern Africa	Algeria, Egypt, Libya[c], Morocco, Tunisia
Southern Africa	Botswana, Lesotho, Namibia, South Africa, Swaziland
Western Africa	Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania[c], Niger, Nigeria, Senegal, Sierra Leone, Togo
Americas	
Caribbean	Antigua and Barbuda, Bahamas, Barbados, Cuba, Dominica, Dominican Republic, Grenada, Haiti, Jamaica, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago
Central America	Belize, Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama
South America	Bolivia (Plurinational State of), Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela (Bolivarian Republic of)
North America	Bermuda, Canada, United States of America
Asia	
Eastern Asia	China (mainland and Taiwan), Japan, Mongolia, Republic of Korea
Central Asia	Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan
Southeast Asia	Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Philippines, Singapore, Thailand, Timor-Leste, Vietnam
Southern Asia	Afghanistan[c], Bangladesh[c], Bhutan, India, Iran (Islamic Republic of)[c], Nepal, Pakistan[c], Sri Lanka
Western Asia	Armenia, Azerbaijan, Bahrain[c], Cyprus, Georgia, Iraq[c], Israel, Jordan[c], Kuwait[c], Lebanon, Oman[c], Qatar, Saudi Arabia[c], Turkey, United Arab Emirates[c], Yemen

Table 7.2 (continued)

Europe	
Eastern Europe	Belarus, Bulgaria, Czech Republic, Hungary, Poland, Republic of Moldova, Romania, Russian Federation, Slovakia, Ukraine
Northern Europe	Denmark, Estonia, Finland, Iceland, Ireland, Latvia, Lithuania, Norway, Sweden, United Kingdom
Southern Europe	Albania, Bosnia and Herzegovina, Croatia, Greece, Italy, Malta, Montenegro, Portugal, Serbia, Slovenia, Spain, Republic of Macedonia
Western Europe	Austria, Belgium, France, Germany, Luxembourg, Netherlands, Switzerland
Oceania	
Australia and New Zealand	Australia, New Zealand
Melanesia	Fiji, Papua New Guinea, Solomon Islands, Vanuatu
Combined Micronesia and Polynesia	Kiribati[a], Micronesia (Federated States of), Samoa, Tonga

[a]Country not included in beef analysis.
[b]Country not included in chicken analysis.
[c]Country not included in pork analysis.

Animal Production Intensity Measures

Across the three meat EI models, animal density and production intensity are the two consistently significant and positive variables. Higher animal densities and production intensity are both associated with higher EIs. The coefficients are less than 1, indicating that the increase in EI is not proportional to increases in animal density or production intensity. For example, a 1 percent increase in chicken density is associated with a 0.30 percent increase in chicken EI. Beef production intensity has the largest coefficient in the beef model, with a 1 percent increase in beef cattle production intensity associated with a 0.84 percent increase in beef EI. This means that the intensity of cattle production is the main driver of beef EIs and indicates that while more intense cattle production practices do provide some GHG efficiency gains, these gains only slow the rate of increase and are not enough to actually reduce the EI of beef (in which case the coefficient would be negative).

Table 7.3

Prais-Winsten unstandardized regression coefficients and standard errors for beef (n = 3,758), pork (n = 3,417), and chicken (n = 3,759) emissions intensities measured as kilograms of CO_2 equivalent released per 100 kilograms of meat produced (100 kg CO_2eq/kg of meat), 1992–2015

	Beef	Pork	Chicken
Animal density	0.164 (0.021)***	0.134 (0.043)**	0.300 (0.035)***
Production intensity	0.839 (0.048)***	[omitted]	0.751 (0.049)***
Manure management percent	0.165 (0.090)	1.867 (0.910)*	-0.646 (0.379)
Carcass yield	-0.658 (0.046)***	-1.018 (0.082)***	-0.907 (0.05)***
GDP per capita	-0.174 (0.024)***	-0.091 (0.040)*	-0.361 (0.031)***
Percent agricultural land	-0.060 (0.020)**	0.075 (0.036)*	0.077 (0.036)*
Percent arable land	-0.101 (0.026)***	-0.100 (0.049)*	-0.235 (0.029)***
Animal number	0.056 (0.010)***	0.028 (0.019)	0.023 (0.016)
Island	-0.287 (0.057)***	-0.135 (0.076)	-0.517 (0.071)***
Eastern Africa	0.103 (0.102)	0.946 (0.334)**	-0.591 (0.395)
Middle Africa	0.503 (0.113)***	1.436 (0.296)***	-0.082 (0.402)
Northern Africa	-0.445 (0.145)**	1.531 (0.453)**	-0.876 (0.390)*
Southern Africa	0.391 (0.212)	0.706 (0.282)*	-0.781 (0.405)
Western Africa	0.340 (0.096)***	1.032 (0.297)**	-0.407 (0.385)
Caribbean	1.073 (0.145)***	0.867 (0.419)*	-0.122 (0.227)
Central America	0.445 (0.147)**	1.136 (0.443)*	-1.095 (0.206)***
South America	0.403 (0.150)**	0.871 (0.426)*	-0.650 (0.217)**
North America (reference)			
Western Asia	-0.419 (0.115)***	1.101 (0.253)***	-0.822 (0.334)*
Southeast Asia	-0.262 (0.181)	-0.651 (0.142)***	-0.724 (0.211)**
Southern Asia	-0.228 (0.092)*	0.157 (0.185)	-0.406 (0.228)
Eastern Asia	-0.365 (0.149)*	-0.555 (0.358)	-0.091 (0.268)
Central Asia	-0.507 (0.139)***	-0.663 (0.316)*	0.451 (0.320)
Eastern Europe	-0.198 (0.148)	0.031 (0.321)	-0.402 (0.100)***
Western Europe	-0.392 (0.120)**	-0.481 (0.139)**	-0.565 (0.105)***
Northern Europe	-0.105 (0.103)	-0.151 (0.175)	-0.307 (0.093)**
Southern Europe	-0.210 (0.121)	0.024 (0.109)	-0.375 (0.122)**
Australia and New Zealand	0.147 (0.119)	-0.031 (0.130)	0.114 (0.144)
Melanesia	0.678 (0.101)***	0.375 (0.146)*	0.306 (0.141)*

Table 7.3 (continued)

	Beef	Pork	Chicken
Micronesia and Polynesia	0.855 (0.163)***	0.237 (0.222)	0.239 (0.108)*
Constant	4.859 (0.396)***	-0.239 (3.812)	8.957 (1.517)***
Rho	0.904	0.913	0.904
R-squared	0.817	0.436	0.795
Chi-squared	6059.010***	32251.060***	19823.630***

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$ (two-tailed)

Manure Management

The percentage of animal emissions that come from manure management has a negative effect on the chicken EI and a positive effect on both beef and pork, but it is only statistically significant in the pork model, where it has a large effect compared to the other variables. A 1 percent increase in the manure management percentage from pigs is associated with a 1.8 percent increase in pork EI. This indicates that the more pigs that are kept in conditions that require manure management systems the higher the EI will be, and that there is not an economy of scale gain in EI from keeping more pigs together.

Carcass Yield

Carcass yield is the only livestock-related variable that is related to lower EIs, with negative and significant effects in all three models. The effect is largest for pork with a 1 percent higher carcass weight associated with a 1 percent lower pork EI. Carcass yield is the largest effect in the chicken model, with a 1 percent higher carcass yield associated with a 0.91 percent lower chicken EI. The reduction in beef EI is not as high, with a 1 percent higher beef carcass weight associated with a 0.66 percent lower beef EI.

Conceptually, the effect of carcass yield on EI makes sense because while larger/heavier animals produce slightly more emissions than smaller animals (they typically eat more, thus produce more manure, etc.) the greater amount of meat they produce results in lower emissions per unit of meat. For example, if two large cattle yielded the same amount of meat as three smaller cattle, the emissions per pound of beef would be lower for the meat from the two large animals, since only two metabolic processes are being supported rather than three for the same amount of meat. However, this example assumes that all the animals are the same age when they are slaughtered; obviously, larger animals that were older when they were slaughtered will have lost some or all of that size efficiency in GHG emissions.

Controlling for Agricultural Context

Affluence—measured as GDP per capita—has a reducing effect on EI for all three meats, possibly through the contributions of livestock production research and technology including, but not limited to, genetic improvements related to meat production through increases in carcass yield.[10] The portion of agricultural land in a country has a statistically significant but small negative effect on beef EI, and small, positive effects on pork and chicken EIs. The portion of agricultural land that is arable in a country has a consistently significant and negative effect on the EIs of all three meats. The significance of these agricultural land variables indicates that the biophysical environmental context of a country's agricultural system matters to the GHG efficiency of its meat production, all else being equal, but without more detailed information on the animal production practices within each country the specific mechanism(s) of these effects cannot be determined. For beef, the number of cattle has a small, but significant and positive effect, on EI.

Controlling for Country Location and Other Factors

Island and region dummy variables are used to control for factors related to geographic location, climate, and cultural and economic conditions that are not otherwise included in the model. Negative coefficients of these variables indicate that the region has a lower EI than the reference region (non-islands, and North America), and positive values indicate higher EIs.[11] The significance of these control variables indicates that there are one or more factors specific to these locations that are not otherwise included in the models.[12]

Islands have significantly smaller beef and chicken EIs than non-islands, all else being equal. Because North America has relatively low EIs for all three meats (see figures 7.2, 7.3, and 7.4), it is interesting to see which regions are associated with having even lower EIs—there is something about these places that make them more GHG-efficient meat producers, other than the factors that are already in the model. The Northern Africa, Western

Asia, Southern Asia, Eastern Asia, Central Asia, and Western Europe regions are all associated with having beef EIs that are significantly lower than those of North America. For pork, only the Southeast Asia, Central Asia, and Western Europe regions are associated with having pork EIs that are significantly lower than North America. For chicken, the Northern Africa, Central America, South America, Western Asia, Southeast Asia, and all four European regions have chicken EIs that are significantly lower than North America's.

Conclusions

The world's top meat-producing regions also generate the most GHG emissions from cows, pigs, and chickens: North America (i.e., the United States), South America (i.e., Brazil), Asia (i.e., China), and Europe (i.e., the EU). These are also places that are known for intense meat production and high corporate concentration (see chapters 2 and 4). However, these regions and countries are among the more GHG-efficient meat producers, according to the narrow accounting of GHG emissions from meat used by the FAO, which includes only emissions coming directly from the animals and their manure. What makes them more efficient by this measure?

Technology and intensification are often expected to reduce a number of dimensions of environmental impacts through improving the efficiency of production (Grau, Kuemmerle, and Macchi 2013; Horlings and Marsden 2011). However, for all three meats, the preceding analyses indicate that while some economies of scale in GHG emissions from more intensive livestock production are possible, these efficiencies do not reduce the GHG EIs of beef, pork, or chicken, but only reduce the amount of increase. This reduced increase has certainly not kept up with the increases in global meat production. This can be seen in figure 7.1, where meat EIs have decreased globally over time but total emissions have increased.

Carcass yield was the only production-specific variable that was associated with lower EIs across all three models, which makes sense from a strictly GHG emissions perspective. Carcass weight also represents technology, in that carcass weight can be influenced by animal genetics along with other factors such as diet. Animals that have been bred for meat production are often selected for larger size and muscle mass, and higher feed-to-meat conversion ratios.[13] However, this effect can be confounded, such as when former dairy cattle are slaughtered for meat. These animals typically have a low carcass yield (they have been bred to put their metabolic energy into milk not meat), but their emissions have been spread out over a huge number of milk calories produced along with the meat, making the meat very efficient on a GHG emissions-per-calorie basis.

Importantly, GHG efficiency is only one type of efficiency, just as global climate change is just one type of environmental impact from meat production. Other types of environmental impact from animal agriculture, such as manure runoff into local water sources, poor local air quality, or land-use change are also important, as are issues of animal and worker well-being, and maintaining food sovereignty in the face of greater corporate consolidation and control over the global food supply.

Notably, this analysis has some limitations. First, the EI variable does not include things like feed production, and certainly not things like land-use change done to facilitate animal production (such as converting forests to pastures). Animals raised in the most intensive systems, CAFOs, require lots of calorically concentrated food that has to be grown somewhere else and then brought to them. Not only does the transportation of this feed release GHGs, but so does the production of the feed, especially if it is a crop like corn that is commonly grown with large amounts of nitrogen fertilizer (Robertson et al. 2013).[14] Not only are these feed production emissions not included in the EI measure, but also, when countries import much of their feed, they can appear to have low emissions from fertilizers (see part I introduction; chapter 4).

Second, while permanent grasslands and pastures have the potential to store carbon (i.e., be "carbon sinks") depending on management practices and grazing intensity (Conant and Paustian 2002; Soussana, Tallec, and Blanfort 2010), pastures produced by clearing forest can represent a serious GHG impact, as well as biodiversity impact. For example, Brazil lost 53 million hectares of forest and gained 12 million hectares of pasture between 1990 and 2015 (author's calculations using FAO data). These emissions would also not be counted in the GHG emissions data used in this analysis.

Considering the details and specific context of a production system, both socially and environmentally, is an important complement to the global perspective offered in this chapter. Local effects of meat production and climate change on people and the environment can easily be obscured by national data. For this reason, studies taking a close look at animal production practices and how they intersect with the local social, economic, and environmental contexts are important (see chapter 5).

In conclusion, GHG emissions from meat production are a topic of great importance as meat production continues to rise globally, along with other sources of GHG emissions. While more intensive livestock production may provide some economies of scale in GHG emissions from meat production, it is clear that these efficiencies are not reducing the overall GHG EIs of beef, pork, or chicken, but only reduce the amount of increase. All else being equal, increased carcass yield may reduce the EIs of meat production, but given the high correlations between meat production and total meat emissions the most sure-fire way to reduce GHG emission from meat is to produce less of it.

Notes

1. Ruminants—cows, goats, and sheep, for example—have a multi-chambered stomach in which microbes assist in breaking down food. This enteric fermentation produces methane as a by-product. Animals with a single-chambered stomach, such as pigs, rabbits, and horses, also produce some methane from their digestion, but much less than ruminants. Poultry digestion includes very little enteric fermentation (Hartung 2003), and the FAO does not report enteric fermentation data for poultry.

2. Between 1961 and 2015, enteric fermentation dropped from 63 percent to 60 percent of total meat animal emissions, while emissions from manure applied to pastures increased from 20 to 23 percent.

3. It is important to note that the FAO GHG emissions data used in this chapter does not include GHG emissions from feed production or transportation. High-intensity meat production will thus have emissions from these sources that are not accounted for and may make places with high-intensity meat production look like they are more GHG efficient than they actually are.

4. The decrease in Asia's pork EI has been sustained since the late 1970s, which corresponds with the pork boom in China described in chapter 4. This increase in pork production in China involved the adoption of industrial production techniques, which contributed to lower EI in pork production, even as total GHG emissions from pork increased.

5. MMT stands for million metric tons. One metric ton (or tonne) is equal to 1,000 kilograms or about 1.1 U.S. tons.

6. These six countries stand apart in terms of chicken emissions. The country next below the EU in chicken emissions, India, produced half as many emissions in 2014.

7. The EI variables were calculated by the FAO based on their data on meat production and GHG emissions calculated using the IPCC Tier 1 formulas and emission factors that include climate/temperature and broad characterizations of livestock production practices (IPCC 2006).

8. Based on the political economy of agriculture literature and/or the STIRPAT literature, I include animal population (P), rather than human population, gross domestic product (GDP) per capita as a control measure of affluence (A), and the animal production variables for technology (T). I also control for different agricultural contexts with the agricultural land variables, and use dummy variables for island location and FAO regions to account for climate and culture differences that cannot be included in the analysis directly due to lack of data.

9. This analysis uses a Prais-Winsten regression in Stata14, which accounts for observations within a country being related to each other and thus not truly independent (as is assumed for ordinary least squares regression) (Beck and Katz 1995, 1996, 2004). The data come from *FAOSTAT*, with different samples for each analysis based on the available data. All three samples cover the period from 1992 to 2015. The beef sample includes data for 177 countries (n = 3,758 country-year observations), the pork sample includes 160 countries (n = 3,417 country-year observations), and the chicken sample includes 177 countries (n = 3,759 country-year observations). All countries included in the analysis had at least seven years of data and all regions included complete data for at least two countries. All nonbinary variables were log transformed prior to analysis, in keeping with the STIRPAT tradition, which makes the analysis results be interpreted as "ecological elasticities" (York, Rosa, and Dietz 2003b). The coefficients of the dummy variables are the multiplier of the dependent variable when the dummy variable equals 1, once the antilog of the coefficient ($e^{\text{coefficient}}$) is taken (York, Rosa, and Dietz 2003b).

10. GDP and carcass yield are moderately correlated for beef (correlation coefficient = 0.61; GDP: VIF = 2.01 and tolerance = 0.498; beef carcass yield: VIF = 1.73 and tolerance = 0.579), pork (correlation coefficient = 0.59; GDP: VIF = 1.82 and tolerance = 0.550; swine carcass yield: VIF = 1.94 and tolerance = 0.516), and chicken (correlation coefficient = 0.73; GDP: VIF = 2.19 and tolerance = 0.456; chicken carcass yield: VI F= 1.75 and tolerance = 0.570), but not enough to notably influence the results of the analysis.

11. To interpret the size of this difference, take the antilog of the coefficient (see note 9). For example, the antilog of the island variable in the beef model is 0.750 or 75 percent of the beef EIs of non-island countries, all else being equal.

12. This is not a problem, as we are capturing much of this variation with the dummy variables. However, to determine what these factors are would require different models using more detailed data.

13. In the case of chickens, this genetic selection can cause animal welfare concerns when combined with high-density production settings—the rest of the chicken's body does not develop well enough to support their large chests, making walking difficult if not impossible for them.

14. Because it is common for only about 50 percent of the nitrogen applied to a grain crop to be used by the crop, much of the rest is lost to the environment, either to streams and groundwater or to the atmosphere in forms that include nitrous oxide (N_2O), which has a global warming potential that is nearly three hundred times that of CO_2 (Robertson et al. 2013).