Positioning for the Future of Beef Production: Focus on Sustainability

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Introduction

Sustainability is about balancing economic, social, and environmental concerns and positive attributes (i.e., the triple bottom line) and having a long-term focus (i.e., meeting the needs of the present without sacrificing the ability of future generations to meet their own needs; UN, 1987). Much of the focus in recent years on beef and sustainability has been on environmental impacts, and in particular, beef's higher environmental footprints (e.g., carbon, water, and land) relative to other foods when expressed per pound or per unit of crude protein (Poore and Nemecek, 2018).

The relative differences in environmental footprints of foods has led to recommendations to consume more plant-based foods, or switch to pork, poultry, and fish over beef. Additionally, the environmental footprints of beef and other animal proteins has been a key focus of so-called "plant-based meats" and is a driving force behind the development of cell culture-derived muscle tissues that are yet to come to market. Ultimately, a prevailing narrative in food-informed and environmentally-concerned consumer, media, and investment circles has been "eat less meat for better human and planetary health" or "less meat, less heat" referring to curbing climate change by consuming fewer animal-derived foods, with a focus on beef.

Context on meat and heat

Broad consensus exists regarding the underlying climate science that increasing concentrations of greenhouse gases in the atmosphere, driven by human activity, are affecting the global climate system. Numerous gases, including water vapor, can trap heat in the earth's atmosphere. This heat-trapping effect, or greenhouse effect, is responsible for keeping the global average temperature at a hospitable level for life on earth. Without the greenhouse effect the global average temperature would be 0°F compared to 59°F with the effect (Ma, 1998). However, recent changes in greenhouse gas concentrations (Table 1) have led to concerns that the global climate will change at a pace that will negatively affect human livelihoods, and the natural ecosystems and agroecosystems that we depend upon.

Most of the observed warming due to increasing greenhouse gas concentrations has come from carbon dioxide (72% of global human-caused greenhouse gas emissions in 2010), with the majority of the concentration increase due to the combustion of fossil fuels and land use changes that have released biogenic carbon (i.e., carbon from soils, plant biomass) and reduced the capacity of atmospheric carbon dioxide to be sequestered via plant biomass (i.e., reduction in photosynthetic capacity of rainforests due to deforestation; IPCC, 2014). The second and third most important human-derived greenhouse gases are methane and nitrous oxide, representing 20% and 5% of human-caused greenhouse gas emissions globally in 2010, respectively. Both gases are primarily derived from microbial processes, with fossil fuel sources playing a more minor role. Agriculture is an important source for both methane and nitrous oxide, with ruminant animal agriculture being a considerable source of methane naturally-derived from ruminant digestive systems (IPCC, 2014).

Discussions of greenhouse gas emissions from beef production often conflate global statistics for U.S.-specific estimates and total livestock emissions with emissions from beef production. The U.N. FAO's latest estimate of global livestock emissions using life cycle assessment (i.e., feed production and deforestation included) was 7.1 Gt of carbon dioxide equivalents or 14.5% of global greenhouse gas emissions. The reference year for the report was 2005 and global human-caused emissions were assumed to be 49 Gt of carbon dioxide equivalents. The FAO's estimate for global beef production was 2.9 Gt of carbon dioxide equivalents or 6% of global emissions. In the United States, direct emissions from beef cattle enteric fermentation and manure represent 0.132 Gt of carbon dioxide equivalents or 2% of U.S. greenhouse gas emissions (0.27% of global emissions), with all direct emissions from livestock, including beef, representing 3.9% of U.S. emissions in 2016. However, for context, within the United States, agricultural emissions of greenhouse gases are completely offset by annual carbon sequestration from land use, land use change, and forestry. Thus, U.S. agriculture and forestry combined in 2016 represented a net sink of carbon emissions (-0.154 Gt of carbon dioxide equivalents; EPA, 2018).

Table 1. Changes in greenhouse gas concentrations in the atmosphere and 100 yr. global warming potentials of each gas. Data from EPA Greenhouse Gas Emissions Inventory 1990-2016 and IPCC, 2014.

Gas	Pre-Industrial concentration, parts/million	Current concentration, parts/million	Global Warming Potential 100 yr.[1]
Carbon dioxide	280	401	1
Methane	0.700	1.823	28
Nitrous oxide	0.270	0.327	265

[1] Greenhouse gases have different potentials to trap heat in the atmosphere and different atmospheric lifetimes, thus a system of global warming potentials (GWP) have been developed to compare across gases on a similar time-scale, expressed in carbon dioxide equivalents. The Intergovernmental Panel on Climate Change (IPCC)'s latest assessment uses the 100-yr. GWP of 1 for carbon dioxide, 28 for methane, and 265 for nitrous oxide.

While reports regarding global food demand relative to the year 2050 often highlight how meat demand will increase per capita, these assessments often mask longer-term trends in animal-derived food consumption by species. Specifically, over the past 5 decades within the United States (Figure 1) and globally, there has been a pronounced shift in increasing consumption of monogastric animal protein foods (pork, poultry) and flat or even declining consumption of ruminant meats. For example, the relative change in per capita consumption from 1961 to 2013 was a decline of 1% for bovine meat, a 100% increase for pig meat, and a 420% increase in poultry meat globally (UN FAO, 2018).

Of course, per capita availability or consumption is not demand, but it seems unlikely that these longer-term trends will shift in a pronounced way in the next 32 years as the global population reaches 9.8 billion persons. If current trends of per capita consumption, population growth, and beef productivity trends continue, the global cattle herd will likely grow by approximately 7% from today's herd of 1.5 billion to 1.6 billion in 2050. Improving the productivity of beef production above current rates could potentially even reduce the size of the global cattle herd by 2050, while still meeting bovine meat demand for 9.8 billion consumers.

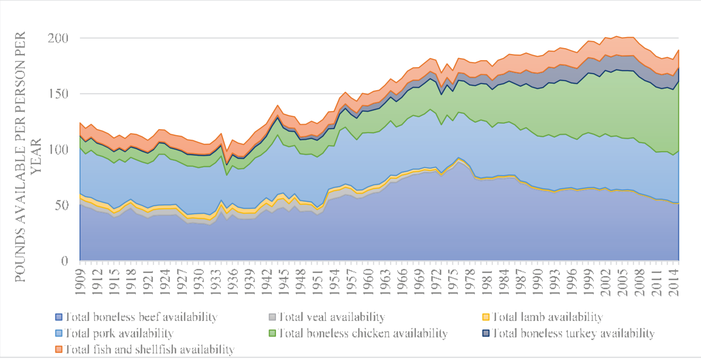

Figure 1. Long-term meat availability trends per capita in the United States from the USDA Economic Research Service Food Availability system for the years 1909 through 2015. These data are before accounting for consumer, retail, and food service losses. Relative to 1909 annual per capita availability, beef was 0.6% higher, red meat (beef, lamb, veal, and pork combined) was 3% lower, and meat overall was 53% higher in 2015.

Cattle herd size relative to beef produced is a critical component that determines the total resource use of beef production within the United States and globally. Per capita beef consumption is sometimes used as a proxy for estimating impacts from beef production, and recent reductions in per capita consumption within the United States have been highlighted as a reason for reduced greenhouse gas emissions. However, this is incorrect. Emissions from U.S. beef production have declined because the U.S. cattle herd has declined, and more beef has been produced per live animal (considering all supporting herd cows, bulls, replacement heifers, and cattle bound for finishing). The same amount of beef produced spread out over a growing population will result in lower per capita consumption, but will not result in a decline in total environmental impacts unless fewer environmental impacts are generated from each pound of beef produced. As Table 2 illustrates the relationship between per capita meat consumption, total direct greenhouse gas emissions from cattle production, and emissions intensity is not clear cut.

Table 2. Total live cattle and buffalo stocks, per capita bovine meat availability, cattle meat emissions intensity, and total emissions from cattle and buffalo meat production for selected countries. All data from UN FAO's FAOSTAT database and relevant to the year 2013. Relationship between per capita bovine meat consumption and total emissions from cattle and buffalo are not clearly positive – Spearman rank correlation coefficient for these selected countries is -0.26.

	Total cattle beef and dairy and buffaloes	Per capita bovine[1] meat availability kg/yr.	Emissions intensity for cattle meat, CO2-eq/kg	Total emissions[2] from cattle and buffalo, Gt CO2-eq.
Argentina	50,996,397	55.48	28.9	0.081
Ethiopia	55,027,080	3.61	146.6	0.050
India	298,400,000	0.81	106.4	0.210
Niger	10,733,314	8.97	71.3	0.010
United States	90,095,200	36.24	11.5	0.136
China	103,582,286	5.23	16.3	0.135

[1] Includes cattle and buffalo meat. Carcass weight basis and before losses.

[2] Includes methane and nitrous oxide emissions from manure management, manure applied to soils, manure left on pastures, and methane gas from enteric fermentation. Only non-dairy cattle emissions included.

Why have ruminants like beef cattle in a food system?

While environmental footprints, such as carbon footprints, are useful tools to benchmark the sustainability of an individual food industry or commodity, like beef, they are also unable to capture all the relevant components of a sustainable food system. Relatively higher environmental footprints for beef compared to other protein-source foods are used by some to advocate for dramatically reduced beef consumption and production within the United States and globally. Essentially, the argument of some against beef is that the social costs of beef production outweigh the benefits, or alternatives to beef would provide greater social benefit. However, a full accounting of the social costs of beef production (e.g., carbon emissions) vs. the social benefits (e.g., human nourishment, ecological benefits, wealth) has not been completely assessed to this author's knowledge.

Multiple factors important to a sustainable food system that are not captured in environmental footprints include:

1. Cattle can convert human-inedible feedstuffs into high quality human-edible protein.

Collection of management and feeding information from over 2,200 beef producers across the United States has been used to generate environmental footprints and estimate feed consumption and conversion (Rotz et al., submitted). From a full life cycle perspective, 1 kg of beef carcass weight produced in the United States requires 13.2 kg dry matter of grazed forage, 5.1 kg dry matter of harvested forage (e.g., hay), 2.6 kg dry matter of grain concentrate (mostly, corn grain), and 1.5 kg dry matter of other feeds that mostly includes human-inedible byproduct feeds from human food, fiber, and biofuels production. Thus, 89% of the 22.3 kg dry matter feed required per kg of grain-finished beef carcass weight produced in the United States is human inedible plant matter.

Because the majority of the feed resources used to generate grain-finished beef in the United States are not in competition with the human food supply, and the protein value of beef to humans is 2.63 times greater than corn grain, our current grain-finished beef system is generating more high-quality protein for the human populace than it is using. However, slight reductions in the corn grain required per kg of beef carcass weight produced can further enhance the protein upcycling value of U.S. beef production (Table 3). Recent research at the global scale observed similar results. For every 1 kg of human edible protein generated from beef production, only 0.6 kg of human edible feed were required; thus, global beef production provides 66% more human edible protein to the human food system than beef cattle themselves consume (Mottet et al., 2017).

Table 3. Human edible energy returns, human edible protein returns, and net protein contribution estimates for grain-finished beef cattle fed varying amounts of corn grain per kg of beef carcass weight produced. In all scenarios, the protein amount and quality (considering amino acid composition and digestibility) of the grain-finished beef produced exceeds the corn grain fed to cattle. This means more human nutritional value is generated by feeding corn grain to cattle and consuming the resulting beef as compared to humans eating the corn grain directly.

Corn grain consumed (kg DM) per kg of grain-finished beef produced (carcass weight basis)	Human-edible energy return[1]	Human-edible protein return[2]	Net protein contribution[3]
2.6	0.48	0.96	2.53
2.4	0.52	1.04	2.74
2.2	0.57	1.14	2.99
2.0	0.63	1.25	3.29
1.8	0.69	1.39	3.66
1.6	0.78	1.56	4.12

[1] Human edible energy return = MJ energy in kg of beef carcass weight/MJ energy in corn consumed per kg of beef. Assumed 80% of corn grain is human edible and corn metabolizable energy content is 13.78 MJ/kg of DM, and beef (choice grade) metabolizable energy content is 12.81 MJ/kg of carcass weight.

[2] Human edible protein return = kg edible protein (crude protein) in kg of beef carcass weight/kg of edible protein in corn consumed per kg of beef. Assumed 80% of corn grain is human edible and crude protein content of corn is 8.65% per kg of DM, and beef crude protein content (choice grade) is 173.2 g per kg of beef carcass weight.

[3] Net protein contribution is human edible protein return * protein quality ratio. Protein quality ratio is the digestible indispensable amino acid score (DIAAS) of beef (111.6)/DIAAS of corn (42.2). Net protein contribution values greater than 1 indicate more high-quality protein generated in the form of beef than the cattle consume (i.e., adding to the human food protein supply; Ertl et al., 2016).

2. Cattle consume forages/roughages that are grown on lands unsuitable for cultivation, thereby expanding the land base available for food production.

As outlined above, the majority of the feed resources used by the U.S. beef industry are human inedible forages. Most of these forages are produced on lands unsuitable for cultivation, or from lands that if cultivated, would be highly erodible. In the United States, there are approximately 800 million acres of land that are considered range and pasture lands (USDA-ERS, 2018). Currently, the only way to generate human food from this land area that represents 35% of the United States is to convert the biomass to human edible products with ruminant livestock – cattle, sheep, and goats. U.S. cattle producers provide land management services and help preserve habitats on hundreds of millions of acres across the nation.

3. Cattle consume byproduct feeds from the food, fiber, and biofuels industries.

Considering human food alone, Fadel (1999) estimated that for every 100 kg of human food produced from crops, 37 kg of byproducts were produced. Using the 1.5 kg dry matter of byproduct feeds fed to cattle from above (Rotz et al., submitted) and assuming 11.8 billion kg of beef production, U.S. beef cattle consume and value-add approximately 18 million metric tons of byproducts annually. While it could be argued these byproducts could be disposed of or used to create compost as a soil amendment, feeding human food byproducts to cattle generates multiple benefits. Byproduct feeds fed to cattle generate human nourishment, wealth, and manure which is a high-quality organic fertilizer. In this way, as with integrated crop-cattle production systems, cattle act as a component of the circular bio-economy, cycling and upcycling nutrients and energy through the integrated food, fiber, and biofuels system.

4. Integrating cattle into row-crop plant agriculture systems can have environmental and socioeconomic sustainability benefits.

Cattle can be and are integrated into crop production systems either at the farm-scale on the same land base or are integrated from a regional perspective to capture synergies between cropping and cattle farming systems. Benefits of integration depend on the production system, soils, and climate, but can include improved nutrient cycling, added farm enterprise diversity (a form of risk management), and the generation of multiple human usable products (i.e., both plant and animal products) from a given land area (Sulc and Franzluebbers, 2014). Examples include crop residue grazing, such as using corn stalks remaining after harvesting corn grain (which can be used for human food, biofuels, animal feed, or other industrial purposes) for cattle feed. Approximately, 70% of surveyed cow-calf producers in the Midwest and Northern Plains of the United States were using crop residue grazing in their production systems, whether owned land or leased (Asem-Hiablie et al., 2016). Another example is grazing winter wheat with stocker cattle in the Southern Great Plains. Approximately, 2 million cattle graze winter wheat pasture each year (USDA-NASS, 2018), which can be subsequently harvested for human-use and milled into flour. One of the byproducts of the wheat milling process, wheat middlings, can then be fed back to cattle – again, this highlights the upcycling role that cattle play in our bio-economy.

5. Beef cattle operations represent over one third of the farms in the United States, and thus beef cattle producers play an important role in the agricultural economy and the social fabric of rural America.

In 2012, there were 2.1 million farms in the United States and 913 thousand were cattle operations (beef and dairy combined). Beef cow-calf operations were estimated at 727 thousand (USDA-NASS, 2012). The cattle industries are responsible for approximately 2.1 million jobs and $165 billion in added value to the U.S. economy (Thoma et al., 2017). Because cattle operations are often located in regions unsuitable for significant cultivated agriculture, they can serve as economic hubs to rural economies supporting other businesses and local services. Additionally, well-managed cattle grazing operations are generating wealth and nutrition from landscapes in a manner than can be highly resilient and viable for the long-term (Heitschmidt et al., 1996), in contrast to the boom-and-bust cycle of some natural resource development. Thirty-nine percent of cattlemen and women donate their time to a civic organization compared to the national average of 7% (Cattlemen's Stewardship Review, 2017).

6. Cattle produce more than edible beef – they are also a source of a variety of ancillary products from leather to pharmaceuticals.

Edible beef sold as muscle meat cuts and ground beef is approximately 42% of the animal's live weight, whereas 44% is available for byproduct production. Byproducts include hides, inedible offal, and edible offal (which includes variety meats). Byproducts from cattle are used for a variety of purposes including in the manufacture of adhesives, ceramics, cosmetics, fertilizers, glues, pet food, chewing gum, photographic films, and leather products. Additionally, glands and tissues from cattle can be sources of epinephrine, insulin, serums, vaccines, and antigens (Marti et al., 2011). To this author's knowledge, no life cycle assessment has examined the economic, social, or environmental consequences if these byproducts derived from cattle were severally limited or eliminated from a food system without cattle production.

What can we do to improve beef's sustainability?

While U.S. beef has made impressive productivity gains in the past 4 decades that have translated into reductions in environmental impacts per unit of beef, opportunities remain to further improve. One way to frame these opportunities is to think about the value proposition beef brings to the food system. Compared to other meats, beef production excels at transforming lower value resources, such as human inedible plants and uncultivatable lands, into a high-quality and desirable protein product, essential micronutrients, and other key ancillary products, such as leather and pharmaceuticals. Our collective challenge is optimizing this upcycling service against potential negative environmental outcomes, and enhancing the social acceptability of beef production.

Key to optimizing the upcycling service of beef production is feed conversion efficiency. Feed conversion efficiency can be approached in multiple ways – dry matter conversion into gain, human edible feed conversion into beef, human edible protein conversion into human edible protein in beef, etc. Reducing human edible feed requirements per unit of beef while still maintaining a highly desirable, marbled product would improve the food system value of beef. From a whole industry perspective, optimizing maintenance energy costs against total beef production, particularly from the cow herd, can potentially improve upcycling and increase beef produced per acre from grazing lands. As Figure 2 demonstrates, the cow maintenance energy costs per kg of beef produced have remained relatively flat for the past two decades. Optimizing cow size to the operation's natural resources and environment has the potential to improve both individual cow-calf enterprise's profitability and whole industry efficiency (Lalman et al., 2018).

Another potential avenue of enhancing beef's upcycling value proposition is finding viable and cost-effective solutions to reduce enteric methane production, or more specifically, decrease the loss of potential metabolizable energy as methane gas. According to the latest EPA greenhouse gas emissions inventory, enteric methane emissions from beef cattle were 4,853 kt in 2016, which is 6.44 × 1010 Mcal of energy. Fractional improvements in redirecting methane energy losses to animal metabolism could improve the efficiency of the entire U.S. beef industry.

Finally, beef producers do affect a large percentage of the land area of the United States for a relatively small number of individuals. Any improvements in grazing management practices and wider adoption of adaptive management techniques would likely enhance the long-term viability of individual operations, enhance ecosystems, and maintain or improve the health of soils.

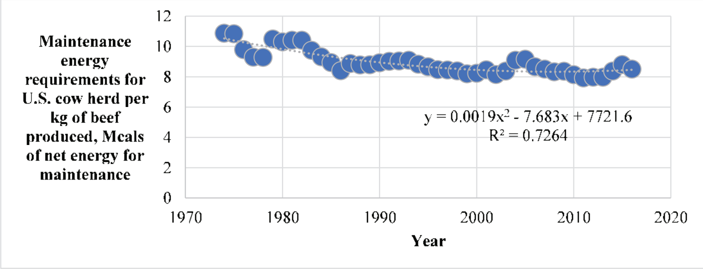

Figure 2. U.S. average cow maintenance energy costs (Mcal of NEm) per kg of beef carcass weight produced. In the past 20 years, cow maintenance energy costs per kg of beef produced have remained relatively flat. Using USDA-NASS cow slaughter weights and annual beef production data, and maintenance energy requirement equation from NASEM, 2016.

Conclusion

Sustainability has been an issue at the forefront of the beef industry for most of the past decade. Given current marketing trends and the real pressures on our food and earth system as the global population grows by 2 billion additional people in the next two decades, sustainability will not be going away as an issue. Increased interest from consumers in where and how their food was produced presents an excellent opportunity for the beef community to show the passion and care that is involved in producing beef. Doing more with less and doing the right thing because it's the right thing to do are central to sustainability. However, with increased interest comes increased scrutiny, thus, the beef community also needs to address misinformation and make changes when needed to maintain social acceptability. At times, this may mean simply presenting what the beef community does daily in an innovative way.

Food for thought: The beef community uses a technology that produces high-quality protein from solar energy locked within human inedible plants. The technology produces a natural organic fertilizer, and is mobile without using fossil fuels. The technology self-replicates.

The technology is cattle. Beef is the original, sustainable plant-based meat.

References

Asem-Hiablie, S., C. A. Rotz, R. Stout, K. Stackhouse-Lawson. 2016. Management characteristics of beef cattle production in the Northern Plains and Midwest regions of the United States. Prof. Anim. Sci. 32: 736-749.

Cattlemen's Stewardship Review. 2017. Available at: *https://www.beefitswhatsfordinner.com/Media/BIWFD/Docs/beef-csr-report-2017-final.pdf* accessed June 7, 2018.

EPA. 2018. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016. Available at: *https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2016* accessed June 7, 2018

Ertl, P. W. Knaus, and W. Zollitsch. 2016. An approach to including protein quality when assessing the net contribution of livestock to human food supply. Animal. 10:1883-1889.

Fadel, J. G., 1999. Quantitative analysis of selected plant by-product feedstuffs, a global perspective. Anim. Feed Sci. Technol., 79: 255-268

Heitschmidt, R. K., R. E. Short, and E. E. Grings. 1996. Ecosystems, sustainability, and animal agriculture. J. Anim. Sci. 74: 1395-1405.

IPCC, 2014: Summary for Policymakers. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Lalman, D. A. Wiseman, E. DeVuyst. 2018. Implications of cow size change. 2018 Florida Beef Short Course Proceedings. Available at: *http://animal.ifas.ufl.edu/beef_extension/bcsc/2018/proceedings/lalman.pdf* accessed June 8, 2018

Ma, Q. 1998. Greenhouse Gases: Refining the Role of Carbon Dioxide. Available at: *https://www.giss.nasa.gov/research/briefs/ma_01/* accessed June 6, 2018.

Marti, D. L., R. J. Johnson, and K. H. Mathews, Jr. 2011. Where's the (Not) Meat? Byproducts from Beef and Pork Production. U.S. Department of Agriculture Economic Research Service, LDP-M-209-01, November 2011. Available at: *https://www.ers.usda.gov/webdocs/publications/37427/8801_ldpm20901.pdf?v=41056* accessed June 7, 2018.

Mottet, A. C. de Haan, A. Falcucci, F. Tempio, C. Opio, and P. Gerber. 2017. Livestock: On our plates or eating at our table? A new analysis of the feed/food debate. Global Food Security. 14: 1-8.

NASEM. 2016. Nutrient Requirements of Beef Cattle, Eight Revised Edition. Washington, DC: The National Academies Press

Poore, J. and T. Nemecek. 2018. Reducing food's environmental impacts through producers and consumers. Science, 360: 987-992. DOI: 10.1126/science.aaq0216

Rotz, C. A., S. Asem-Hiablie, S. Place, and G. Thoma. Submitted, under review. Environmental footprints of beef cattle production in the United States.

Sulc, R. M. and A. J. Franzluebbers. 2014. Exploring integrated crop-livestock systems in different ecoregions of the United States. Europ. J. Agronomy. 57: 21-30.

Thoma, G., B. Putman, M. Matlock, J. Popp, and L. English. 2017. Sustainability assessment of U.S. beef production. Available at: *https://www.beefresearch.org/CMDocs/BeefResearch/Sustainability%20Completed%20Project%20Summaries/Sustainability_Assessment_Executive_Summary.pdf* accessed June 7, 2018

UN. 1987. Our Common Future - Brundtland Report. Oxford University Press, p. 204.

UN FAO. 2018. FAOSTAT: Food and agriculture data. Available at: *http://www.fao.org/faostat/en/#home accessed* June 7, 2018

USDA-ERS. 2018. Major Land Uses. Available at: *https://www.ers.usda.gov/data-products/major-land-uses.aspx* accessed June 7, 2018

USDA-NASS. 2012. 2012 Census Publications. Available at: *https://www.agcensus.usda.gov/Publications/2012/#full_*report accessed June 7, 2018

USDA-NASS. 2018. Cattle. Available at: *http://usda.mannlib.cornell.edu/usda/current/Catt/Catt-01-31-2018.pdf* accessed June 7, 2018

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